IGM 83-113-087
Etude No. 87

POLYMER CONCRETE

A TECHNOLOGICAL AND ECONOMIC STUDY

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SYNOPSIS

The development of polymer concrete composites began over twenty years ago in a number of different countries. Not much seems to be known about the subject in Canada, however, where it seems to have received scant attention.

To correct this state of affairs, the Industrial Materials Research Institute (IGM) of National Research Council Canada asked the Centre de recherche industrielle du Québec (CRIQ) to undertake a study to identify the technological and commercial potential in Canada of resin concrete (or polymer concrete - PC), resin-impregnated concrete (or polymer-impregnated concrete - PIC) and polymer-portland cement concrete (PPCC) in order to recommend research plans adapted to Canadian needs.

First, the study reviews the state of technology and application of polymer concretes throughout the world. It discusses the main commercial products or structures and gives examples of the application of each of the three types of composite studied. The amount of attention devoted to each type depends on its current use. The study does not include a critical review of all the technical literature dealing with the properties of polymer concrete.

Part I of the study: State of technology of polymer concrete

This part gives the main properties of resin concrete - mechanical, thermal and chemical. The advantages of resin concrete products in terms of maintenance, cleaning and resistance to abrasion are also outlined. In addition, attention is given to resin concrete reinforced with fibres, rods and fabrics.

Subsequently the study presents a collection of data concerning the fabrication of resin concrete products - types of resin used, aggregates, preparation of mixtures and moulding techniques.

In discussing the use of resin concrete products, the study takes examples from the construction industry, sanitary products, industrial products and outdoor furniture and examines the development of commercial uses in Europe (facing panels, pipes, expressway repair, construction and repair of bridges, furniture, and the fabrication of machine frames), in Japan (manholes for service mains, construction of tunnels ...) and in the United States (repair of roads and bridges, and thermal applications).

The characteristics, properties and production methods of polymer impregnated concrete (PIC) and polymer-portland cement concrete (PPCC) are discussed as are several examples of applications in the United States and Japan.

Part I also deals with gel-coated concrete and the relative advantages of the various polymer concrete composites.

Part II of the study: Canadian products and uses. A user survey

The second part of the study examines the development of the Canadian polymer concrete industry.

Although Canadian expertise in the field of polymer concrete is rather limited, a number of projects that have attempted to take advantage of the superior properties of polymer concrete composites are worthy of mention. The most useful applications are for facing panels for public buildings, street furniture and components used in protecting bridge columns against abrasion and corrosion and in expressway repair.

Knowledge and commercialization of polymer concrete products is less advanced in Canada than it is in many other industrialized countries. The study presents the viewpoint of manufacturers and users of polymer concrete products (engineers, architects, etc.) regarding the factors that are limiting the use of these products in Canada.

A number of suggestions are made for research projects adapted to Canadian needs and the conclusion is reached that potential users do not have enough information on the possibilities offered by polymer concrete materials.

Part II ends with an overview of the market potential for applications such as road, bridge and viaduct repair and maintenance, street curbs, electric insulators and industrial products.

Part III of the study: Research and development opportunities

Part III recommends research plans adapted to Canadian needs. These plans are discussed in the context of world R&D in the field of resin concrete and as part of the total R&D effort in Canada.

To stimulate the development of the Canadian polymer concrete industry, the study concludes that potential users (engineers, architects, designers, etc.) must be given more information.

1.0 INTRODUCTION

The development of polymer concrete composites began in a number of different countries over twenty years ago. New applications are being studied and developed continually. Quite a number of commercial products throughout the world are currently using these composites in various fields of application.

The final product is unique in that it combines the technical advantages of concrete and polymers at a reasonable cost.

The three main categories of concrete that contain polymers are:

1- resin concrete or mortar (or polymer concrete - PC) prepared by mixing a resin or monomer with an aggregate;

2- polymer-impregnated concrete (PIC) prepared by impregnating normal concrete with a monomer which is polymerized in situ;

3- polymer-portland cement concrete (PPCC) prepared by adding a resin or monomer to portland cement during the mixing stage; the admixture is polymerized in place.

The properties and applications of these three types of polymer concrete are very different from each other and only add to the many technical possibilities of cements and plastics.

The field of polymer concrete does not seem to be very well known or to have received much attention in Canada. Countries like Britain, West Germany and Japan however, have developed technical expertise over the past twenty years or so that has led to a great number of commercial applications of this new type of material.

This study, initiated at the request of the Industrial Materials Research Institute (IGM) of National Research Council Canada, seeks to identify the technological and commercial potential of polymer concrete in Canada in order to recommend research plans adapted to Canadian needs.

The study consists of three parts, as follows:

1) the state of technology and application of polymer concretes throughout the world;

2) an overview of the Canadian polymer concrete industry;

3) establishment of possible research and development plans to foster the use of polymer concrete in Canada.

1.1 Purpose of the study

As originally agreed between the IGM and the Centre de recherche industrielle du Québec (CRIQ), the main object of the study is "to identify the technological and commercial potential of PC, PIC and PPCC-type polymer concretes in Canada and recommend research plans adapted to Canadian needs".

This objective can be subdivided as follows:

1- to examine the principal commercial uses of the various types of polymer concrete composite in the USA, Europe and Japan;

2- to indicate the properties and advantages of polymer concrete to demonstrate its application potential;

3- to discuss the properties and application potential of gel-coated portland cement;

4- to give an overview of the Canadian polymer concrete industry and identify the constraints that are delaying or restricting the use of polymer concrete in Canada;

5- to identify Canadian market potential on the basis of the polymer concrete market situation in the USA and Europe;

6- to collect the views of Canadian producers, architects and consulting engineers on research and development needs with respect to polymer concrete.

1.2 Methodology

1.2.1 State of technology

To determine the state of technology and application of polymer concretes throughout the world, information was gathered by means of:

- an in-depth study of the technical literature published on the subject;
- contacts established with the main research centres and manufacturing enterprises to identify their products.

During this phase of the study, data bases were consulted and over two hundred documents, reports and articles were scrutinized. In addition, requests for information were addressed to over fifty manufacturers, suppliers or research organizations in the USA, Europe and Japan.

1.2.2 Situation in Canada

The following methods were used to determine the state of the art in Canada:

- a survey conducted among all interested parties in Canada;
- interviews of a representative sampling of manufacturers and research organizations involved in polymer concrete.

Fifty manufacturers of synthetic marble products and 250 consulting engineering firms were polled. The data collected allowed us to evaluate both the level of knowledge of potential users and certain factors that are delaying the use of polymer concrete in Canada. In addition, a number of Canadian products and projects were identified during this part of the study; a description is given of them.

1.2.3 Research and development opportunities

Research and development plans were established by comparing research needs as identified by Canadian interested parties with the state of world technology and international research trends in polymer concrete.

PART I

A REVIEW OF THE COMMERCIAL APPLICATIONS OF POLYMER CONCRETES

The development of polymer concrete composites began in a number of different countries over twenty years ago. New applications are being studied and developed continually. Quite a number of commercial products throughout the world are currently using these composites in various fields of application.

Part I examines the chief commercial uses of the three types of polymer concrete composite: polymer concrete (PC), polymer-impregnated concrete (PIC) and polymer portland cement concrete (PPCC). A number of applications are discussed at length so that the potential of each type may be appreciated. The amount of attention devoted to each of the three types depends on its current use. The study does not include a critical review of all the technical literature dealing with the properties of polymer concrete.

2.0 RESIN CONCRETE

2.1 Definition

For the purposes of this report, the term polymer concrete or resin concrete is defined as a material composed mainly of a thermosetting resin (5 to 25%) and mineral loadings of various aggregate gradings (75 to 95%). This deliberately general definition includes the terms resin mortar, synthetic concrete, synthetic marble and cultured marble, thus eliminating any semantic confusion that these terms might create. All belonging to the same family, the differences between them generally relate to particle size and type of mineral loading or to their field of application.

The mineral loadings used are varied (silicate, carbonate, sand, rock dust, etc.) and the resins acting as binders are of the thermosetting type (phenolic resin, urea-formaldehyde, polyester, polyurethane, epoxy, acrylic, furan, etc.). For reasons of cost, polyester resins are the most popular, however.

2.2 History

The first research into resin concrete was carried out in the early fifties. Countries such as West Germany, Britain, the USA, the USSR and Japan were interested in this material and used it for very specific projects in which its mechanical and aesthetic characteristics as well as its property of corrosion resistance were utilized. Some countries have recommended its use or even require it for certain applications.

Resin concrete cannot replace hydraulic portland cement concrete in a majority of applications and in particular in structural applications on account of its high cost and its creep properties at average temperatures. However, utilization of the various characteristics of resin concrete opens up new possibilities and expands the existing market for new products, thus providing competition for traditional products which have not previously allowed competition and for materials as diverse as ceramics, steel, cast iron, natural stone and plastics.

3.0 PROPERTIES

3.1 Mechanical properties

Table 1 shows the chief physical and mechanical characteristics of polyester resin-based concretes. Average values are given based on standard formulations tested at 23°C.

TABLE 1: Average physical properties of resin concretes

CHARACTERISTICS	AVERAGE VALUES
DENSITY (1) kg/dm^3	2 - 2.1
TRACTION (1)	
- BREAKING STRESS (MPa)	17
- ELONGATION AT BREAK (%)	0.5
FLEXION (1)	
- BREAKING STRESS (MPa)	30
- DEFLECTION AT BREAK (mm)	0.5
- ORIGINAL MODULUS OF ELASTICITY (MPa)	15
COMPRESSION (1)	
- BREAKING STRESS (MPa)	100
CHARPY IMPACT RESISTANCE (NO NOTCH) (1): kJ/m^2	1.75
COEFFICIENT OF EXPANSION (1) (mm/mm x ^{o}C)	25 - 30 . 10^{-6}
WATER ABSORPTION (1)	0.5 % maximum
THERMAL CONDUCTIVITY (2) (kcal/mh ^{o}C)	0.8 - 2
CREEP COEFFICIENT (2)	3
FRIABILITY (2) (according to DIN 521 08: cm^3/cm^2)	.025

Sources: (1) C. Michaux, INIEX, Belgium: Les bétons de résine, applications dans le domaine de la construction, Symposium: Evolution récente des matériaux de construction: 28-29 April 1981.

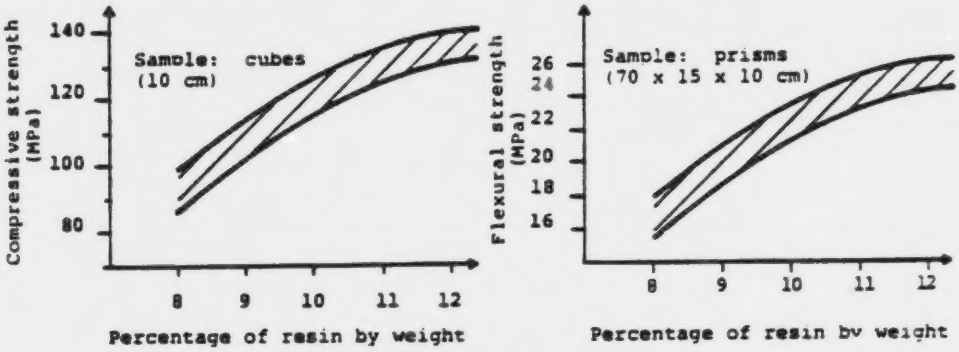
(2) R. Kreis, Possibilités d'application du béton de résine synthétique: Export Market, Vogel-Verlag, No. M10/1972.

As indicated in Table 2, the mechanical properties of resin concrete vary slightly according to the type of aggregates, the aggregate gradings and the amount of resin polymerization. Figure 1 illustrates the variation in flexural strength and compressive strength of a concrete formulation according to resin content.

TABLE 2: Comparison of the properties of various types of resin concrete

PROPERTY	UNIT	TYPE OF RESIN CONCRETE				PORTLAND CEMENT CONCRETE
		Polyester	Epoxy	PMMA	Poly-urethane	
Density	kg/dm^3	2.0 - 2.4	1.95 - 2.4	2.0 - 2.4	1.9 - 2.1	2.3
Water absorption	%	0.03- 1.0	0.02 - 1.0	0.05-0.6	1.0	7.0
Compressive strength	MPa	50 - 150	50 - 150	70 - 210	60 - 75	35
Tensile strength	MPa	8 - 25	8 - 25	9 - 11	8 - 25	2.5
Flexural strength	MPa	15 - 45	15 - 50	30 - 35	9 - 27	8
Modulus of elasticity	MPa	20 - 40	20 - 40	35 - 40	10 - 20	25
Poisson's ratio	-	0.16-0.30	0.30	0.22-0.33	0.30	0.16
Abrasion (Boehme friction disc)	cm	0.10-0.30	0.10-0.30	-	0.20-0.35	-
	g	-	-	-	-	130
Adhesion to steel (shear bond)	MPa	4 - 12	5 - 14	-	-	-
Adhesion to concrete (shear bond)	MPa	4 - 5	4 - 6	5	1.5	-
Linear thermal coefficient of expansion	$10^{-6}.K^{-1}$	10 - 30	10 - 35	10 - 19	30	$10\text{-}12^{-6}$
Chemical resistance	-	Good/ Very good	Very good	Very good	Good/ Very good	Inade-quate

Source: L. Czaarneck, Resin Concrete Group, University of Poland: «Resin Concrete and Polymer Impregnated Concrete: a comparative study», Polymers in Concrete, Third International Congress, KORIYAMA, Japan: May 13-15, Proceedings: pp. 99-110.



Source: W. Klöker, H. Niesel: "Polyesterbeton und Kunststein"
Betonwerk, No. 7, 1974, pp 490-496,
No. 4, 1975, pp 157-160,
No. 5, 1975, pp 252-255.

FIGURE 1: **Short-term tensile and flexural strength of polyester concrete at ambient temperature (Unsaturated polyester resin: 1 110, in accordance with German Industrial Standards (DIN) 16 946)**

The density of synthetic resin concrete is between 2 and 2,4 kg/dm^3, depending on the mixture and the degree of compaction. It varies only slightly from that of hydraulic concrete. Thus, because of the mechanical properties of resin concrete which are on average four times better than those of concrete, resin concrete panels, etc. can be at least 50% lighter than their portland cement concrete counterparts allowing for possible reductions in wall thickness and in the dimensions of the pieces.

3.2 Thermal properties

Because of the nature of the binders in resin concrete, the latter's behaviour is influenced by temperature. For a standard polyester-base formulation, the deflection temperature in accordance with ASTM D648 varies between 80° and 130°C. The specimen will begin to bend at temperatures around 100°C. For current applications, however, in which the material is self-supporting (supporting elements have not yet been contemplated), temperature does not give rise to any problems within a reasonnable temperature range, as can be seen from Table 3A, which shows the characteristics of resin concrete at different temperatures. (1)

TABLE 3A: Flexural strength of a polyester concrete at different temperatures

MECHANICAL PROPERTY	TEST TEMPERATURE (°C) -40	23	60	75
BREAKING STRESS (MPa)	29	30	29	29
DEFLECTION (mm)	0.3	0.3	0.3	0.4
ORIGINAL MODULUS (MPa)	19	17	17	15.5

Various rapid aging tests have demonstrated that resin concrete has good freeze-thaw stability, corrosion resistance and stability in extremes of temperature. Table 3B gives an example of the stability of polyester-base resin concrete when subjected to a certain number of temperature cycles, each of which involves 12 hours'exposure to -40°C followed by the same period of exposure to +80°C.

TABLE 3B: Flexural strength of a polyester concrete subjected to temperature cycles (-40°C to +80°C)

MECHANICAL PROPERTY	NUMBER OF CYCLES					
	0	5	10	30	50	75
BREAKING STRESS (MPa)	30	30	29	30	29	33
DEFLECTION AT BREAK (mm)	0.3	0.3	0.3	0.3	0.3	0.3
ORIGINAL MODULUS (MPa)	17	16	15.5	15.5	15.5	17.5

Source: C. Michaux, INIEX, Belgium: "Les bétons de résine, applications dans le domaine de la construction", Symposium: Evolution récente des matériaux de construction, April 28-29, 1981.

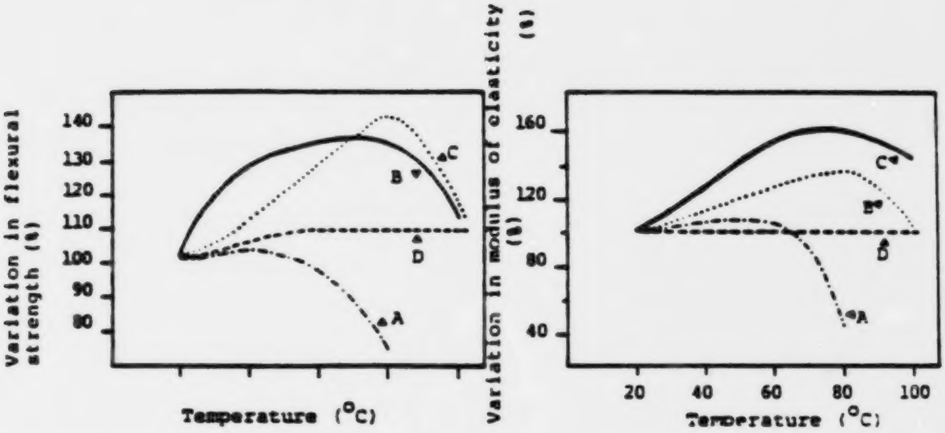
The behaviour of polyester concrete at high temperatures during a short period depends on the type of polyester resin used, as indicated in Figure 2. Figure 3 shows that polyester concrete made from resin B, type 1130, subjected to a load of 30% of its initial strength for one month at 60°C scarcely distorts at all. Current studies and more than 14 years' experience show that polyester concrete can resist considerable stress during prolonged periods even at high temperatures, provided the appropriate resins are used. (2)

One argument often brought up against the use of resin concrete is its assumed combustibility even though its reaction to fire is quite acceptable. After exposure to fire for one hour, polyester concrete retained 30 to 45% of its original resistance while portland cement concrete kept only 16% of its resistance under the same conditions. The portland type concrete actually displayed some cracks. (3)

Resistance to fire is of paramount importance in cases where resin concrete is used as facing elements or for interior decoration. Resin concrete behaves very well in fire even without a special additive. A standard polyester-resin-base formulation conforms to Class 2 (slow spread of flames) of the Standard on the spread of flames on the surface of a construction material (British Standard No. 476/17). The addition of fireproofing agents or aluminium hydroxide to the mixture improves its fire resistance at little cost.

3.3 Chemical properties

Tests clearly demonstrated the high chemical resistance of polyester concrete. After samples were soaked in various chemicals for 15 months, the percentage of retained compressive strength was determined, the values obtained being shown in Table 4. By way of example, it was noted that after a brief soak in industrial waste, portland-cement concrete was destroyed where as polyester concrete resisted this stress without sustaining damage (Figure 4).



FORMULATION OF RESINS A, B, C, D

			Proportion by weight
1.	**BINDERS**		
A.	Unsaturated polyester resin, type 1110 (DIN 16, 946)		100
	Diethylaniline (10%)		1
	Bp paste (50%)		3
B.	Unsaturated polyester resin, type 1130		92
	Styrene		8
	Diethylaniline (10%)		1
	Bp paste (50%)		3
C.	Unsaturated polyester resin, type 1140		92
	Styrene		8
	Diethylaniline (10%)		1
	Bp paste (50%)		3
D.	Unsaturated polyester resins, type 1140 specifically chemical resistant		
	Leguval K 41 (with amine accelerator)		45
	Leguval W 41		45
	Styrene		10
	Bp paste (50%)		3
2.	**AGGREGATES**		
	Quartz gravel	7 - 16 mm	35
	Quartz sand	3 - 6 mm	26
	" "	2 - 3 mm	11
	" "	1 - 2 mm	9
	" "	0.2 - 1 mm	6
	" " H 33	0.1 - 0.31 mm	13

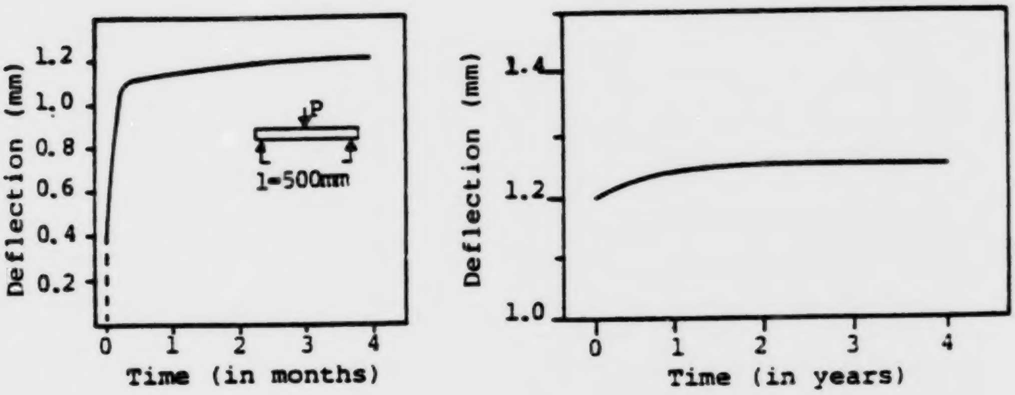
3. **HARDENING** At 20 - 22°C and 7 days of curing at this temperature, then 3 days

Curing: At 40, 60, 80 or 100°C and testing immediately after lowering the temperature

Until test: In the 1 - 2°C marginal zone. Test on prisms 70 x 15 x 10 cm

Source: W. Klöker, H. Niesel: "Polyesterbeton und Kunststein" Botonwerk, No. 7, 1974, pp 490-496, No. 4, 1975, pp 157-160, No. 5, 1975, pp 252-255.

FIGURE 2: Variation in polyester concrete strength in relation to test value at ambient temperature (100%)



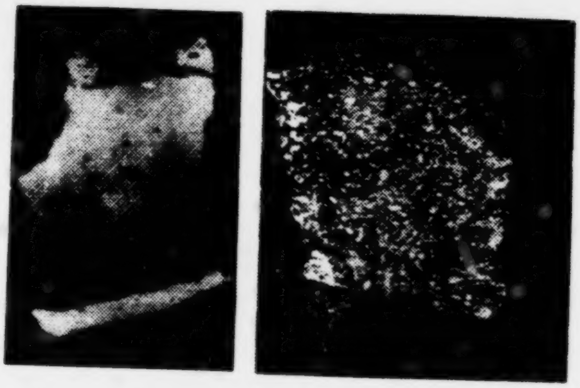
Source: W. Klöler, H. Niesel; "Polyesterbeton und Kunststein"
Betonwerk, No. 7, 1974, pp 490-496
No. 4, 1975, pp 157-260
No. 5, 1975, pp 252-255

FIGURE 3: Long-term behaviour of polyester concrete subjected to 30% of its initial strength and maintained at 60°C.

Tests also proved that polyester concrete is impermeable to water. A water absorption level of less than 1% by weight means that polyester concrete retains only water adhering to its surface and that this water does not penetrate into the concrete. This characteristic is responsible for polyester concrete's very high resistance to freeze-thaw conditions even if it is exposed to all the elements, to permanent sprinkling and to extreme temperatures which is not the case with a portland type concrete. By using resin concrete, damage caused by freezing can be entirely eliminated even without a protective gel coat.

TABLE 4: Chemical resistance of a polyester concrete after 15 months of exposure to various environments

CHEMICAL		% OF COMPRESSIVE RESISTANCE IN RELATION TO INITIAL VALUE
Hydrochloric acid	5%	93
Sulphuric acid	30%	76
Nitric acid	6%	65
Acetic acid	20%	64
Formic acid	20%	75
Caustic soda	5%	65
Ammonia	5%	87
Washing soda	10%	76
Ethyl alcohol	50%	80
Sea water	-	88



Source: RESPECTA documentation (Germany)

FIGURE 4: Comparative strength of two types of concrete exposed to industrial waste

3.4 Maintenance and cleaning

Irrespective of its mechanical and chemical resistance, resin concrete has a unique surface appearance, it lends itself readily to casting in a variety of moulds and can be easily cleaned and maintained, even in the presence of graffiti. This is a very useful quality if we want to preserve and maintain, at little cost, buildings and other external structures that are continuously exposed to a sometimes highly polluted atmosphere and are too often subject to vandalism.

Table 5 shows the results obtained when resin concrete slabs covered with a transparent gel coat were cleaned using rags impregnated with organic solvents. This operation was carried out 3 to 8 days after application of the various varnishes and paints. In the cases in which the organic solvents had no effect (Nos 4, 6, 21 and 23), the varnish or paint was removed by means of nitric or hydrochloric acid and the gel coat remained intact. (1)

3.5 Surface finish and abrasion resistance

As in the case of portland cement concrete, the surface quality of cast elements of synthetic resin concrete depends on the mixture, compaction and the surface of the mould. Nevertheless it was found that the surface was much smoother than that of cement concrete. This results in a much more rapid run-off of water and other liquids contaminated by solid particles such as clay, sand and gravel since the friction caused by the concrete is much weaker. This quality can be utilized by choosing drainpipes with a reduced internal diameter.

TABLE 5: Results of cleaning gel-coated resin concrete

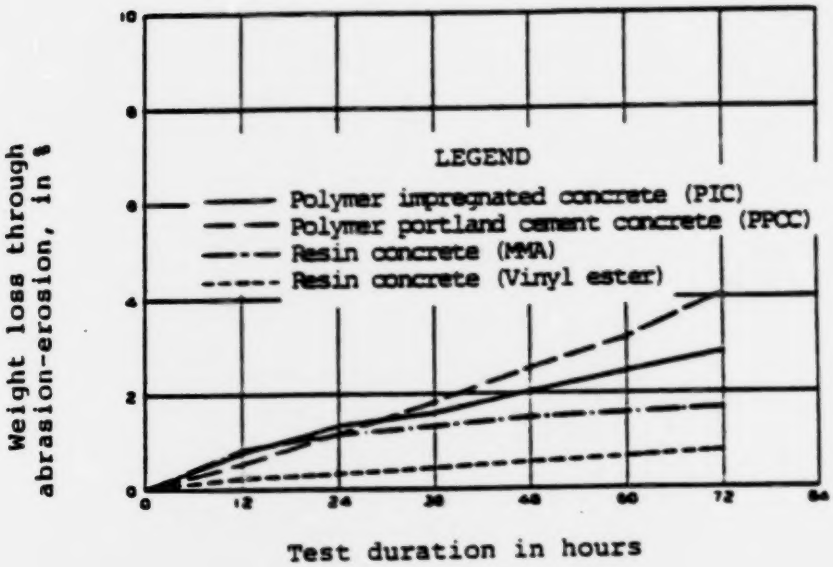
KEY TO SYMBOLS:

• : EASY TO REMOVE - NO CHANGE
•• : REMOVED WITH EFFORT: SOMETIMES SLIGHT TARNISHING
••• : DIFFICULT TO REMOVE: OFTEN ADULLING EFFECT
0 : NO EFFECT

SAMPLES		SOLVENTS			
N°		ACETONE	METHANOL	BENZENE	METHYLENE CHLORIDE
1	MAT BUILDING VARNISH	•	••	••	•••
2	TINTED GLOSS VARNISH	•	••	••	•••
3	METAL VARNISH	•	••	••	•••
4	SATIN BUILDING VARNISH	•	0	0	•••
5	ACRYLIC AUTOMOBILE ENAMEL	•	•	•	•
6	MAT BUILDING ENAMEL	0	0	0	0
7	GLOSS BUILDING ENAMEL	••	0	•••	••
8	SATIN BUILDING ENAMEL	••	0	•••	••
9	SYNTHETIC AUTOMOBILE ENAMEL	•	••	••	•
10	PICTURE PAINT	••	••	•••	••
11	OIL PAINT	••	0	•••	••
12	ALUMINIUM PAINT	•	0	•	•
13	EXTERIOR LATEX	•	•	•	•
14	INTERIOR LATEX	REMOVED WITH SOAPY WATER			
15	PVC PRIMER	•	•••	•	•
16	LEAD CHROMATE PRIMER	•	•••	••	•
17	ZINC CHROMATE PRIMER	•	•••	••	•
18	NEUTRAL AUTOMOBILE PRIMER	•	•••	•••	•

Source: C. Michaux, INIEX, Belgium: «Les bétons de résine, applications dans le domaine de la construction», Symposium: Evolution récente des matériaux de construction, April 28-29, 1981.

Resin concrete has better abrasion resistance than does portland cement concrete. This high resistance is the result of its compact structure and the use of long-lasting nonporous aggregates such as silica. Resin concrete has already been used as interior lining for ball mills on account of its good abrasion resistance and its excellent adhesion. Its abrasion resistance can be put at 0,025 cm^3/cm^2 according to DIN 52108 (4). Figure 5 compares the abrasion resistance of various types of concrete.



Source: T.C. Liv. T.B. Husbands, Structure Lab. U.S. Army Eng. Waterway Exp. Station: "Abrasion Erosion Resistance of Polymer Concretes", Polymers in Concrete, Third International Congress, KORIYAMA, Japan, May 13-15, pp 800-814.

FIGURE 5: Abrasion and erosion resistance of various types of concrete

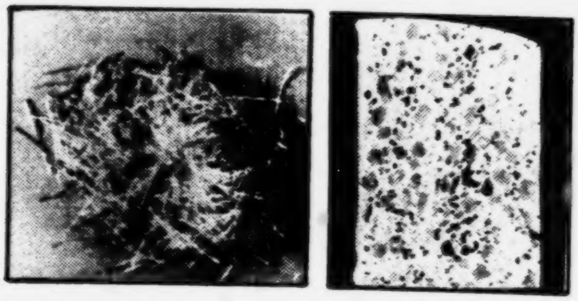
3.6 Reinforced resin concrete

The properties of nonreinforced resin concrete are sufficient for many applications that are not subject to a great deal of shock. Owing to its aesthetic qualities and its mechanical and chemical resistance, however, it also lends itself readily to applications subjected accidentally of periodically to stress through impact such as flagstones, street furniture and curbstones.

To realize the full potential of resin concrete, various reinforcement tests were carried out with glass fibre and metal fibre (Figure 6). Glass fibre-based reinforcement consists of three types: short fibres, bars and rods, and mats and fabrics.

Short fibres

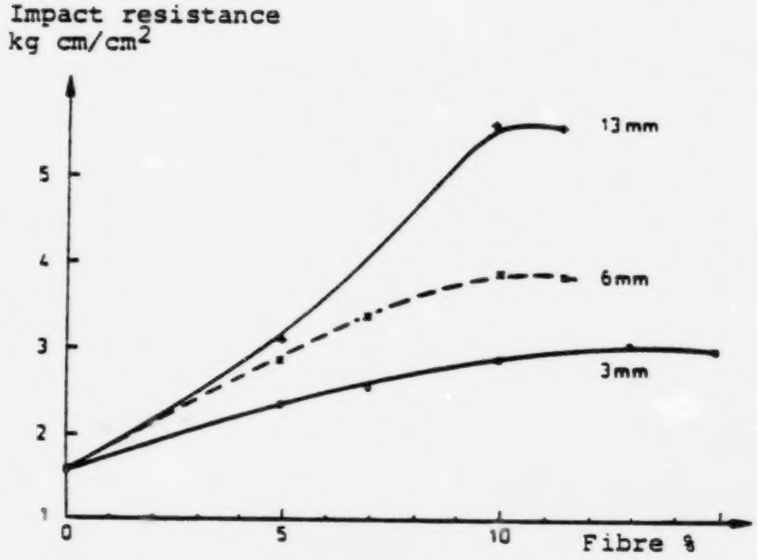
Tests with short fibres have shown that the increase in impact resistance by the addition of fibre will have a upper limite (see Figure 7). From an economic point of view, a 10% level of short glass fibres is the optimum which it would not be remunerative to exceed. This level is calculated on the basis of the quantity of resin since any reinforcing effect that short fibres have is exerted mainly on the resin matrix.



Source: RESPECTA documentation (Germany)

FIGURE 6: Polymer concrete with steel fibres integrated into the mass during a continuous cycle

In such resin concretes, the proportion of minerals will depend on the percentage of short fibres. Indeed, glass fibres absorb proportionally more resin than do the mineral loads (chalk and crushed limestone) used in the experiment shown in Figure 7. As expected, an increased fibre content necessitates an adjustment of the formulae in order to preserve the same operational characteristics. That means a reduction in mineral loading and an increase in the percentage of resin.



Source: C. Michaux, Derniers développements dans le domaine des bétons de résine, Annales des mines de Belgique, November 1980, pp 1051-1065.

FIGURE 7: Charpy impact resistance according to fibre content (ISO: R 179)

Bars and rods

When we wish to increase the resistance of square or rectangular-based modular elements, the first thing we think of is reinforcement steel embedded a few millimetres below the surface. Unlike the case of portland cement concrete, positioning the steel so close to the surface of the concrete is permitted with resin concrete because its impermeability is an effective protection against corrosion even if it is a very thin layer. Glass fibre rods have advantages over steel bars, however, in terms of both anchorage and expansion in relation to the resin concrete matrix. Moreover, the system proves superior when there is a risk of water penetrating an accidental crack or the base, which is not always protected.

During the fabrication of structural elements, bars embedded in resin concrete have served as stiffeners for large components while at the same time acting as reinforcement that transmits the weight to the end supports. They have been used, for example, for trims of monolithic balconies over 2 metres in length. In other cases, e.g. facing elements, bars have provided a solid base for metal inserts, which are anchored to them and carefully positioned so as to correspond to the exact connecting points of the supporting structure. Since all the metal inserts are attached to the bar, the latter will also serve to distribute the stress resulting from the anchorage of the facing element. (5)

Because of the superior qualities of resin concrete and its capacity to enclose tightly metal inserts or reinforcing bars, cast elements may be reduced in volume, either by decreasing their thickness or by hollowing them out while preserving their dimensions. Thus, a useful way of producing posts or columns is to reduce the heart of the material by substituting a low density core (foam, wood, etc.) or emptying it out (casting the material around hollow tubes).

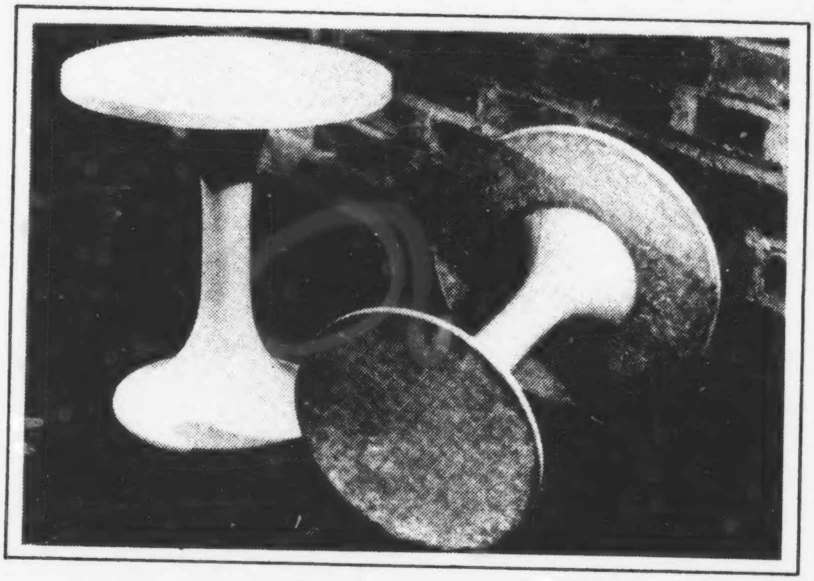
Mats and fabrics

The use of mats and fabrics makes for increased flexural strength and, it there are accidental cracks, stops the product from breaking into a large number of pieces which would render subsequent repair impossible and, in the case of suspended elements, constitute an environmental hazard.

In resin concrete, mats and fabrics are used in a variety of ways, according to the product to be fabricated. They can be utilized in successive layers, a few millimetres apart, in the mass of the finished product; the positioning and amount of these reinforcing layers will depend on the stress to be distributed. It must be noted, however, that the use of the layers is costly because concrete has to be poured with each layer and this has to harden sufficiently before the next layer can be put down. This tedious procedure is necessary to prevent the impregnated mats and fabrics from coming away from the underlying layer of concrete or losing their shape when the following layer is vibrated.

Usually, mats and fabrics are used only to reinforce one of the exterior faces of a finished product. After pouring and vibrating, one or more layers of mats and fabrics are applied separately or simultaneously to the accessible face of the product. This face, which is the opposite side of the one that will eventually be covered with a gel coat, is in contact with the mould; after release from the mould, it will become the underside of the finished product. This procedure has been used to make flat slabs (for table tops, etc.), large thin panels, benches, etc. (see Figure 8).

The mechanical properties obtained after reinforcement are excellent (5). Thus, the strain at break of an ornamental panel a few millimetres thick which was initially 29,4 MPa was raised to 83 MPa by reinforcing one of the faces with a glass mat (45 g/m^2). The use of short steel fibres of the type used in portland cement will increase the mechanical properties of resin concrete even further. A machine developed by the German company Respecta makes it possible for short fibres to be incorporated in the mixture in a continuous process.



Source: J. Bricteux and C. Michaux, INIEX, Belgium; "Amélioration des caractéristiques des bétons de résine par incorporation de fibres de verre".

FIGURE 8: Stools whose undersides (top and base) have been reinforced with glass fibre mats and fabrics

4.0 FABRICATION

It may seem as though the production of resin concrete, especially the unsaturated polyester-based type, is within easy reach of many industrialists as long as they are willing to make a small investment. This is far from the truth. Many enterprises that have started manufacturing resin concrete products without studying the properties of resin concrete or observing certain rules for its manufacture have seen their projects come to nothing. (1) In the United States alone, over 42 businesses failed in their attempt to develop precast resin concrete structural panels. (6)

The casting of elements that have been well polymerized and possess optimal characteristics requires not only adequate equipment and a great deal of care but also the regulation of very important parameters such as working temperature, raw material temperature and humidity and the stability of the various components of the formulations.

4.1 Types of resin used

The following thermosetting resin groups are currently used as binders for mortar and resin concrete:

1. unsaturated polyester resins (UP);
2. epoxy resins (EP);
3. isocyanate or polyurethane resins (PUR);
4. methacrylate resins (MMA);
5. phenolic and phenol-formaldehyde resins (PF);
6. furan resins.

For each category, the most attractive resins are those which harden at temperatures between 0 and 40°C and whose viscosity is between 200 and 6 000 cp. (2)

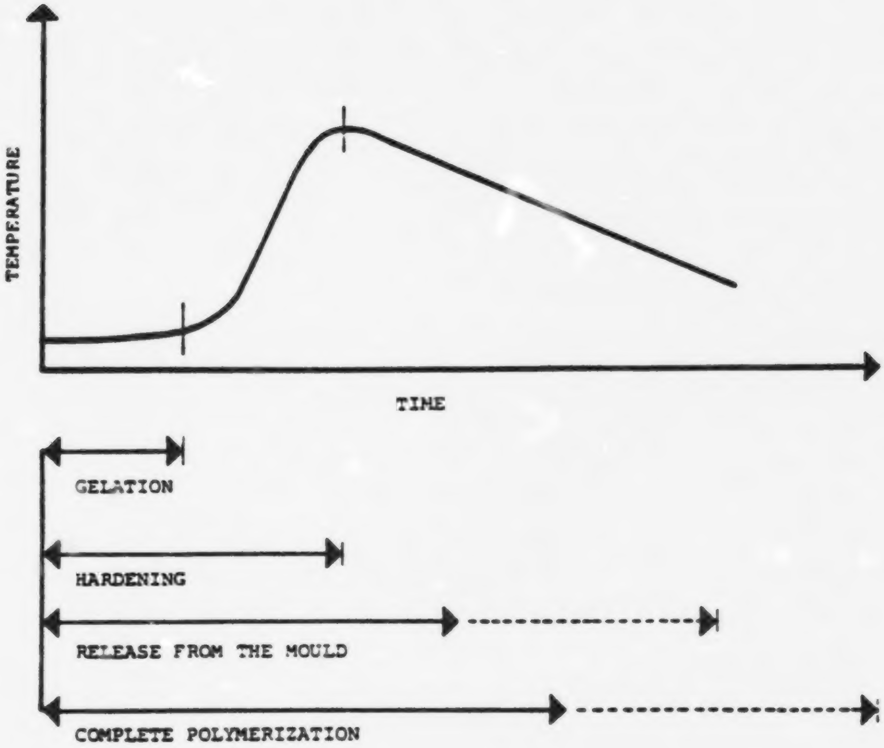
The unsaturated polyester resins are by far the most popular in the prefabrication of resin concrete products today, and 90% of applications use an all-purpose grade of resin. Since the strength of resin concrete depends largely on the aggregate (85-90% by volume), there is no need to use expensive resins to increase the strength. Any break in the concrete under a load will occur in the aggregate, the resin-aggregate bond being stronger than the aggregate's internal links.

The most frequently used polyester resins (molecular weight 1 000 to 10 000) are commercially available in the form of 60 to 80% solutions in copolymerizable monomers. These monomers, essentially styrene (in rare cases mixed with acrylates and methacrylates), have a dual function:

1. to reduce the viscosity and thus facilitate the operation;

2. to bring about simple and rapid hardening at ambient temperature.

Hardening consists of combined polymerization of the unsaturated groups. During hardening the monomers are chemically incorporated into the plastic material being formed (cross-linking) and heat is emitted (70-100 kcal/kg) (see Figure 9).



Source: W. Klöker, H. Niesel
Polyesterbeton und Kunststein
Betonwerk No. 7, 1974, pp 490-496
No. 4, 1975, pp 157-160
No. 5, 1975, pp 252-255

FIGURE 9: Typical polymerization cycle of polyester resin concrete

During the hardening process, all thermosetting resin systems show an exothermic reaction and contraction, whether hardening is the result of polycondensation, polyaddition, polymerization or copolymerization. Reaction heat depends on the system's reactive groups and it is also related to the degree of cross-linking and contraction. Generally speaking, resins that are highly reactive and undergo considerable cross-linking give off more heat and contract more, though they possess a higher modulus of elasticity and greater resistance to deformation through heat than do more tractable types that are subject to less cross-linking. (2)

Epoxy and polyurethane resins can be hardened through reactions of polyaddition. Up to now, they have achieved only little prominence as binders for prefabricated resin concrete products. Nevertheless, they can be used as binders for mortars and coating products, etc. Polyurethanes are relatively expensive and, since they are slow reactors, they require a long time to harden. Despite their sensitivity to humidity before and during the production process, polyurethanes are used as binders for finishes. The cost ratio of polyester, polyurethane and epoxy resins is 1/1, 7/3 to 6 (2).

Phenolic and furan resins are used mainly in special applications such as chemical plant construction. In the case of these polycondensates, one must guard against the possible corrosive effect of the acid hardeners needed by these resins, especially when the structural elements have to be reinforced with steel. (2)

The methacrylate monomers that harden in the cold state have for some time been more popular as coating and binders for resin concrete but they are more expensive than the usual unsaturated polyester resins. Their advantages are their low viscosity, their low rate of contraction during setting (,01 to ,1%) and a thermal coefficient of expansion equivalent to that of portland cement concrete. The main disadvantage of MMA resin is its flash point at 11°C - which constitutes a safety hazard and requires special equipment and production methods to be developed. (8)

To reduce costs, the quantity of resin used for a particular application should be minimal. As in cases where the binder is a portland cement, the resin should coat each particle of aggregate or filler - which means that a low viscosity resin should be used as the binding agent. (9) As can be seen from Table 6, the percentage of resin used in resin concretes is about 10%.

It was realized at a very early stage that the proportion or resin should be minimized so as to lower costs without diminishing the properties of the resin concrete obtained. In 1968,the French company SERNA developed a patented polyester concrete formulation, viz. Beroc, containing as little as 3% resin for concretes and 4,5% for mortars.

TABLE 6: Proportion of materials (by weight) in various types of resin concrete used in Japan

		TYPES OF RESIN CONCRETE			
Function	Material	Polyester concrete (by Okada)	Polyester concrete (by Ohama)	Epoxy concrete (by Ohama)	Polyurethane concrete (by Ohama)
Binder	Resin	Unsaturated polyester 10	Unsaturated polyester 11.25	Epoxy and hardener 10	Polyurethane (containing the fillers) 20
Filler	Calcium carbonate	12	11.25	10	---
Aggregates (dimensions)	.Fine sand .Coarse sand .Gravel	(0.1 ~ 0.8) 20 (0.8 ~ 4.8) 25 (4.8 ~ 20) 33	(<1.2) 38.8 (1.2~5) 9.6 Crushed andesite (5~20) 29.1	(<1.2) 20 (1.2~5) 15 (5~20) 45	(<1.2) 20 (1.2~5) 15 (5~20) 45
Other		Short glass fibres Catalyst (Peroxide) Accelerator	Methyl ethylketone Peroxide Cobalt octoate	---	---

Source: Y. Ohama, "Development of Concrete-Polymer Materials in Japan": Polymers in Concrete, Second International Congress, Univ. of Texas, Oct. 25-27, 1978, pp 121-137.

4.2 Aggregates

Unlike the situation with portland type concrete, when resin is used as the binding agent, the concrete obtained has the strength of its largest aggregate, i.e. any splitting takes place in the aggregate and adhesion between the resin and the aggregate is generally superior to the strength of the aggregate itself. Usually four different gradings, if not fewer, will suffice. The size of the largest aggregate depends on the maximum thickness of the piece to be produced; it is limited to 1/4 of that thickness. (8)

Generally speaking, any dry, nonabsorbant aggregate can be used as filler. The most popular are gravel, silica, sand, crushed stone, clay and expanded glass. The aggregate grading has a direct bearing on the quantity of resin required to make the mixture sufficiently fluid for casting. It must be such as to keep the size of voids to a minimum. Moreover, the surface density of the aggregates affects the viscosity of the resin-aggregate mixtures: a fine aggregate may require as much as 30% resin. The preferred formulations, however, generally use about 10% resin.

For reasons of cost, it is necessary to achieve an optimal density of aggregates with a minimum void size since the voids will have to be filled with the matrix i.e. the resin and very fine particles. (10) Very fine aggregate is generally provided by silica dust (under 1 millimetre in diameter) although other finely crushed rock having sufficient chemical resistance may also be used. Even if any dry, nonabsorbant aggregate may, in principle, be used, the final properties of the mixture will be influenced by the type and shape of the aggregates (round, angular, etc.). (8)

The optimal cost of a resin concrete formulation is, therefore, related to an adequate particle size chosen in advance; aggregate gradings must remain constant during production. The separate handling of dry aggregates until they are mixed with the resin will prevent segregation problems from arising during factory production.

From the production standpoint, the chief advantage of resin concrete is its very short curing time. A few minutes is all that is needed with an appropriate mixture of resin and reagent. To reap the benefits of this characteristic, the constituents must be carefully measured and mixed. This can be achieved by using automatic blending equipment.

4.3 Preparation

Aggregates and polymers can be mixed in a predetermined ratio by means of horizontal blade mixers as used in the concrete industry or by using continuous mixing equipement of the type designed by Respecta about 10 years ago (Figure 10). The viscous mixture is subsequently poured into a mould and vibrated to ensure adequate compaction. Figure 11 gives a plan of a factory for the mass production of panels.

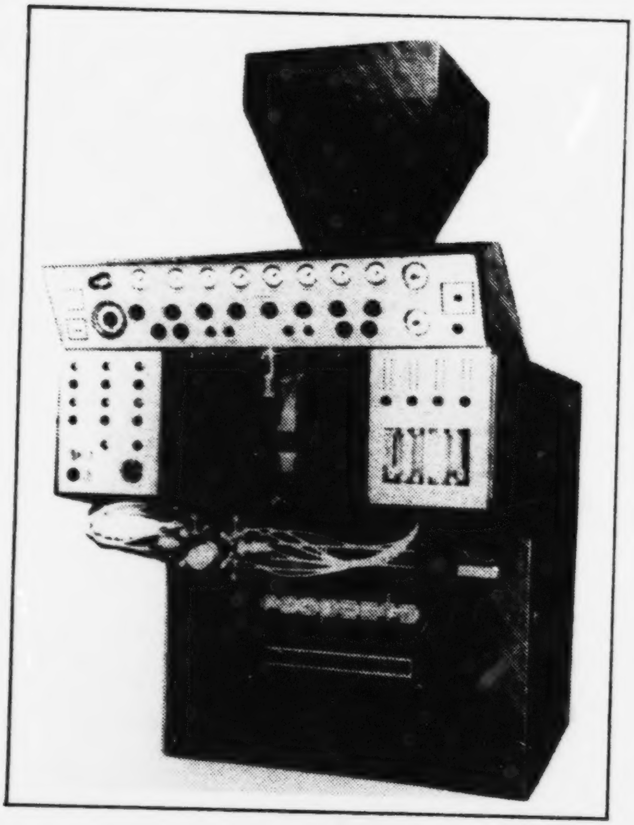
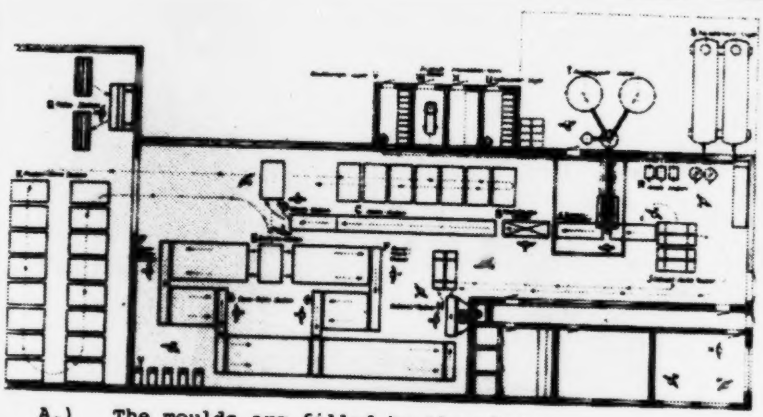


FIGURE 10: Mass moulding equipment for resin concrete: Respecta, model DB-31 (capacity 15-70 lb/minute)



A.) The moulds are filled by the mixer
B.) Vibrating table
C.) Roller conveyor; the concrete gels in the mould
D.) The moulds are turned upside down on a trolley
E.) After setting, the panels are released from their moulds and placed on another trolley for final setting
F.) The empty moulds are cleaned and the mould releasing agent is added
G.) The mould releasing agent is polished
H.) Application of gel coat
I.) After gel coating, the moulds are placed on a trolley and taken to the filling area
K-Q.) After final setting, the panels are cleaned and packed
R-X.) Storage of raw materials

Source: Technical documentation, Respecta Inc. (Germany)

FIGURE 11: Plan of a factory for the mass production of panels or slabs

Respecta Inc. manufactures equipment for the mass production or resin concrete mixtures. The capacity of the machines varies from 10 to 150 kg/minute, the resin/aggregate-filler ratio is adjustable up to 1/30 and the maximum aggregate particle size is about 1 cm. The machines function as follows: the various ingredients of the mixture (aggregate, resin, reagent and, if necessary, colouring) are loaded separately and brought together in the mixing chamber, where they are blended for about 1 second, after which the mixture is poured straight into the mould.

This machine heats the resin and maintains it at a constant temperature, which is higher than ambient temperature. This reduces viscosity and permits precise regulation of output. This peculiarity is important in the case of polyester resins, whose viscosity depends heavily on temperature below 50°C.

By heating the resin to 55°C, it becomes much more liquid and lends itself much more readily to cross-linking which gives the resin concrete its optimal mechanical properties.

Colouring of the resin concrete can be done uniformly in the concrete mass. Contrasting effects of colour can also be achieved to imitate marble. The base colour can be added in liquid form during mixing or it can be added as a powder with the aggregates. The contrasting effects are produced by colours in paste form injected into the mixing chamber, the time of injection and quantities being regulated to create various reproducible effects. Moreover, this machine has an automatic cleaning system which uses a minimum amount of solvents and functions each time the machine comes to a stop.

> "The development of largely automatic machines for the mass production of thermosetting resin concrete constitutes a substantial technological advance which has provided stimulus for the manufacture and use of polyester resin concrete products". (2)

The use of these machines for the transportation, dosage and mixture of the resin with the reagents (the hardener and the accelerator) and aggregates makes this process more economical, especially where mass production is concerned.

For the machine to be used efficiently, it must run in continuous cycles. Thus, filled moulds are transported and stored during the entire setting period. Setting can be achieved at ambient temperature or in a heated state, according to the type of resin or polymerization activator used.

Although automatic installations have come into their own, batch production is still worthwhile especially small scale production e.g. for massive elements for which relatively high aggregate gradings are indicated (e.g. 25 to 30 millimetres) and for the production of in situ concrete. (2)

For batch production, the aggregates and binder (the resin, hardener and accelerator) are weighed separately and added during mixing. After an appropriate mixing period (about 1 to 5 minutes according to aggregate gradings, the percentage of resin and the viscosity), the mixture is poured into a mould lined with a mould releasing agent and compacted.

The prepackaged method is another resin concrete batch production method utilized in situ. It is applied chiefly to repair road surfaces using methyl methacrylate (MMA) resin. The hole to be repaired is cleaned and filled with aggregates prepared in advance. The resin is then poured over the aggregates to saturation point. The drawback with this system is that the finest aggregates tend to form a deposit on the bottom. MMA is used here for its low viscosity.

4.4 Casting

The polymer concrete flows straight from the machine into the mould. Good compaction of the material is then required to obtain optimal properties. Most of the pieces are compacted on a vibrating table, the frequency of the vibration being based on the size and shape of the piece. The vibration time should not be too long, however, so as not to cause segregation of the resin and aggregate-filler. (10)

Experience has shown that the type of surface finish depends, as it does with portland cement concrete, on the mixture used, on the degree of compaction and on the surface of the mould. Nevertheless, resin concrete products display a much more regular surface than do their concrete counterparts.

The fabrication of smooth elements having precise dimensions requires stable moulds with torsion-resistant quality surfaces. Cast pieces without cores can be removed from the mould safely and easily once shrinkage has begun. Shrinkage is easy to recognize from the edges of the mould. On the other hand, mould cores ought to be removed before the resin concrete shrinks too much since shrinkage causes a mechanical bond between the concrete and the mould core. Of course, the nature of the material used for the moulds, their dimensions, their conicity, etc. must be taken into consideration in each particular case. The question of when and how a piece is best released from the mould can be answered only through practice.

Products such as eave troughs and caissons can be released from the mould before polymerization is complete and stacked after a very short time. Panels, on the other hand, must be stored on a flat surface until they have cooled down completely if we want them to remain straight. As long as the element is still warm, it is elastic and can warp. In exceptional cases, an after-bake treatment could prove useful to reach an optimal degree of hardening more quickly. In most cases, however, it is enough to store the elements for one day after release from the mould and then placing them outside. (8)

When polymerization is complete, the material can be treated like stone. It can be polished, sanded, cut, screwed into, etc. However, these operations involve expenses that one generally tries to eliminate by using more elaborate moulds when the number of pieces to be produced justifies it.

Moulds can be produced from a variety of materials: wood, steel, aluminium, stainless steel, glass fibre-reinforced plastic, silicone, polyethylene and teflon. Each material has a different life expectancy and price tag. Consequently, the choice must suit the product to be fabricated and the line of production. Steel and aluminium are very suitable for mass production. Steel and wooden moulds lined with laminated plastic (the arborite type) have produced excellent results in the fabrication of panels. Although polyurethane and teflon do not require mould releasing agents, they are note used much because of their high cost. Since the surface of the resin concrete reproduces exactly the surface of the mould, the latter must be in a highly polished state if we want articles with a glossy finish such as sanitary products. The use of an appropriate mould releasing agent is very important and angular aggregates in the mixture must be prevented from destroying the thin film of mould releasing agents in the mould. (10)

In cases where individual moulds are used (to cut down on the number and hence on the cost), the mould releasing time should be as short as possible. To achieve this end, the resin must start to harden or polymerize soon after contact with the catalyst and aggregates (very short gelation period). The gelation period must, however, be sufficient to allow for pouring of the concrete and its compaction in the mould. This makes it necessary to reduce mixing time to a minimum in a mass production cycle. The combined use of continuous mixing equipment and resins formulated to obtain high reactivity enables the manufacturer to take full advantage of the rapid production potential of resin concrete.

5.0 USES

Resin concrete is a new product that offers increased possibilities to designers and other potential users. Its properties are midway between those of plastics and concrete. Resin concrete is not meant to replace portland cement concrete in structural applications since it is more expensive and is subject to greater creep at temperatures above 30°C or so. The unique characteristics of resin concrete, however, open up new markets where its particular properties can be fully utilized.

In fields of application where concrete does not meet the relevant requirements or can satisfy them only in part, other materials must be chosen. Resin concrete has the very qualities that cement concrete lacks or possesses only to a small degree, viz. high mechanical resistance, excellent chemical resistance, impermeability to water, rapid setting, easily acquired shape and colour, easily maintained finish, resistance to freeze-thaw conditions, etc. Resin can also compete successfully with other materials such as glass fibre-reinforced plastics, asbestos cements, steel, aluminium, wood, marble, granite, etc.

Resin concrete's fields of application are already very diverse. The following are some examples:

Construction:

- Facing panels (Fig. 12)
- Plain or heating floor slabs (Figs 13 & 14)
- Window frame (Figs 15 & 16)
- Stairs (Figs 17 & 18)
- Conduit for electric wires (Fig. 19)

- Sewage pipes (Fig. 20)
- Pipes for surface water drainage (Fig. 22)
- Catch basins (Fig. 25)
- Repair of road surfaces
- Expressway median strips
- Lateral panels for expressways

Sanitary products

- Sinks
- Bathroom furniture such as table tops, shower bases, baths, etc.

Outdoor furniture, private or public, such as tables, chairs, benches, flower boxes, wastebins, etc. (Figs 24 & 25)

Corrosion-resistant industrial products

- Machine bases
- Electrolytic vats
- Oil/water separation tanks (Fig. 26)
- Industrial floors
- Sewage pipes (acid or alkali)
- Drainage ditches (Fig. 27)
- Chemical containers (Fig. 28)
- Channels for water treatment plants (Fig. 29)
- Transformer bases (Fig. 30)
- Surface water headers (Fig. 31)

Table 7 lists prefabricated products utilizing some feature or other of resin concrete.

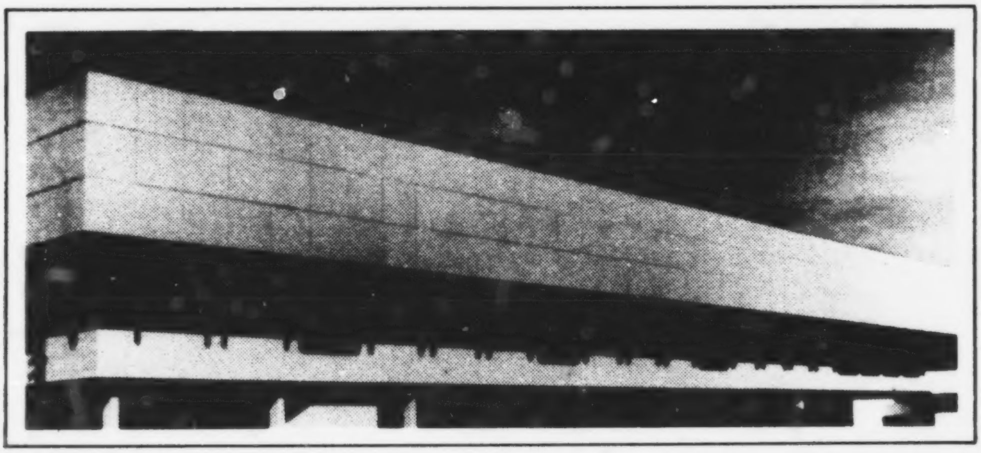
TABLE 7: **List of resin concrete products displayed by Respecta at a 1980 exhibition**

1. Cover plate
2. Sedimentation basin
3. Sewage pipe
4. Wall facing
5. Expressway median strip (USA)
6. U-shaped water ditch
7. Bath
8. Industrial bath lining
9. Oil/water separator
10. Bidet
11. Flower box
12. Patio slab
13. Settling tank
14. Floor lining for: filling station
    - sugar refinery
    - dairy
    - factory using chromic acid
15. Structural element for bridges (reinforced with FRP rods)
16. Bridge deck
17. Well pipe
18. Semicircular channel for chemical plant sewage
19. Structural element in chlorine and zinc electrolysis
20. Ornamental tile
21. Tank for embedding in the ground
22. Steel fibre-reinforced road surface slab
23. Facing element for buildings
24. Window stool
25. Frame
26. Breaker plate
27. Flat roof element
28. Conveyor drum
29. Animal feeding troughs
30. Counterweight for: washing machine,
    - elevator, etc.
31. Safe
32. Boundary stones
33. Hot plate with element incorporated into the mass
34. Electric insulator
35. Cable drum

TABLE 7: List of resin concrete products displayed by Respecta at a 1980 exhibition (cont.)

36. Basement window
37. Acoustic lining for compressor
38. Synthetic granite, marble, onyx, shale and asbestos
39. Noise protection system
40. Airstrip drainage system
41. Machine base
42. Rolling lateral surfaces of machinery
43. Mineral tank for port installations
44. Wastebin for public or commercial buildings
45. Cellular element in humidification device
46. Oil separator
47. Observation tunnel
48. Pipes of various sizes
49. Pipe lining
50. Venetian blind box
51. Acid storage tank
52. FRP and resin concrete sandwich pipes
53. Imitation-shale facing
54. Mud retainer component
55. Polishing device
56. Solar heating component
57. Equipment for cowsheds
58. Rainwater drain for streets
59. Annunciator panels
60. Junction box
61. Table top
62. Table-tennis table top
63. Electric transformer base
64. Stair
65. Foundation for safes
66. Window and door frames
67. Door handle
68. Channels for water purification plant
69. Foundation for weighing machines
70. Frames for water and gas meters, etc.

Source: Respecta documentation (Germany)



Source: SAFANA et CIE documentation (France)

FIGURE 12: Polyester concrete panels for a public building (Sainte-Lo, France)

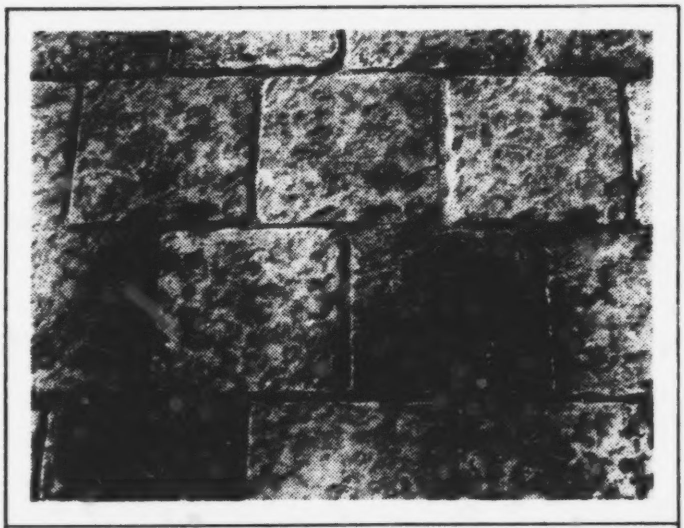


FIGURE 13: Floor tiles imitating stone (for interior and exterior use)

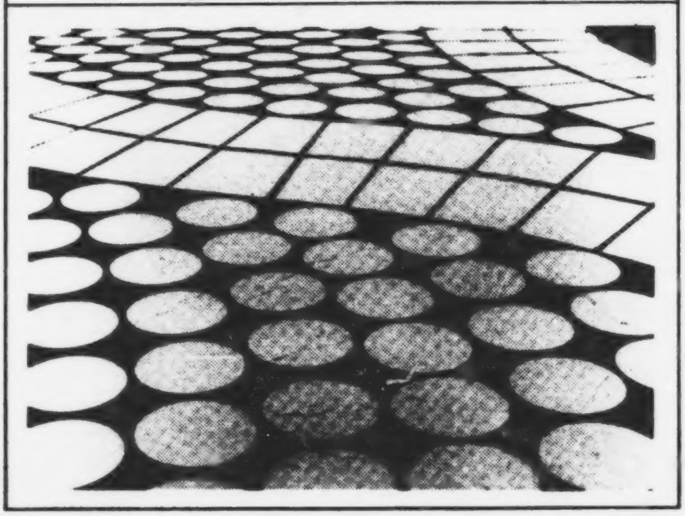


FIGURE 14: Geometrically shaped interior or exterior tiling

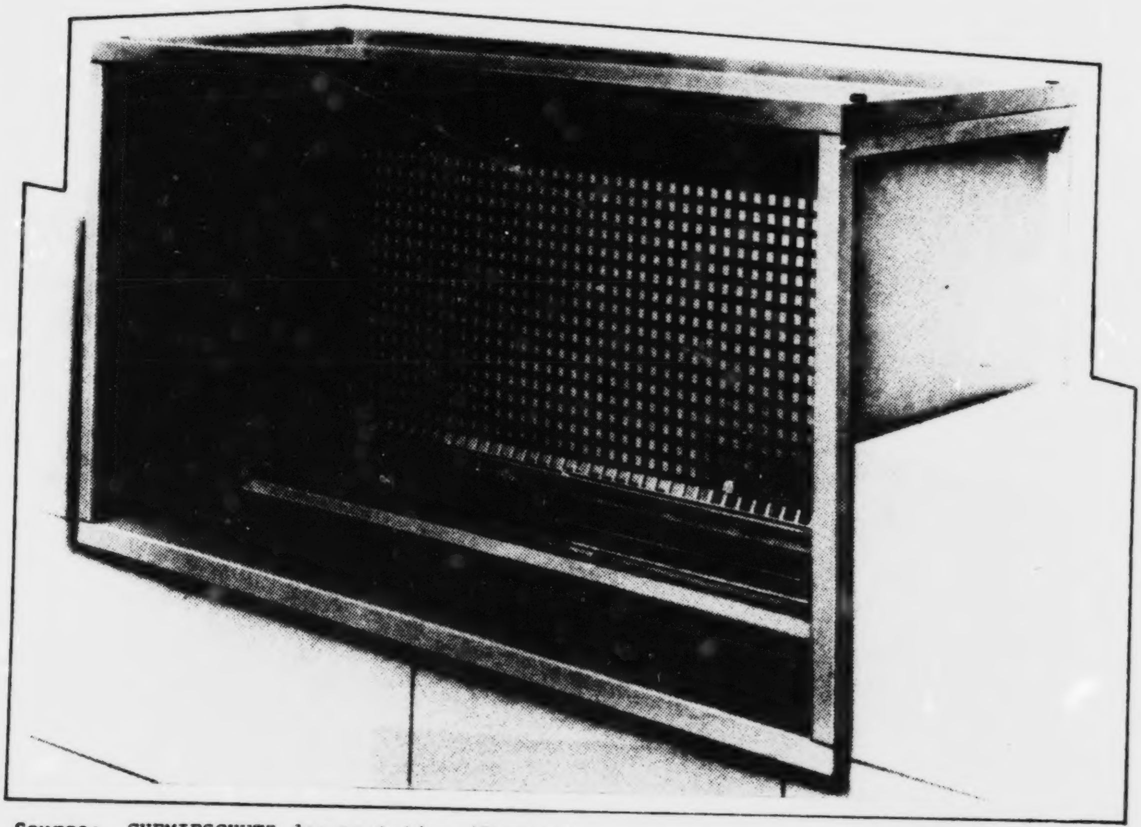
Source: SAFAMA ET CIE documentation (France)

Source: RESPECTA documentation (Germany)

FIGURE 15: **Imitation marble stairs**

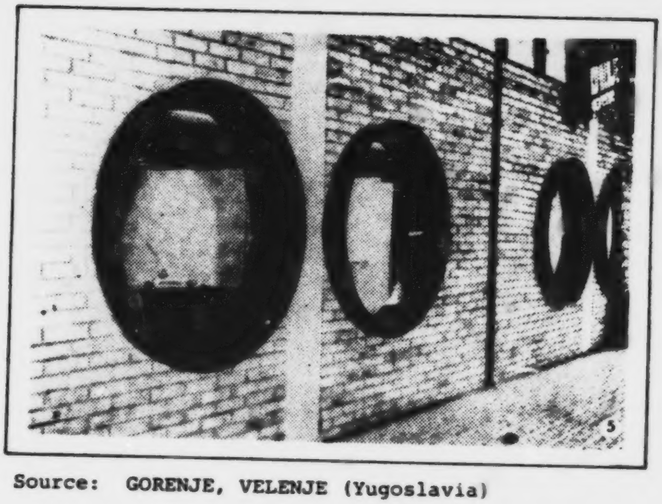
Source: POLYESTERBETON documentation (Germany)

FIGURE 16: **Electrically heated stairs (acrylic concrete)**



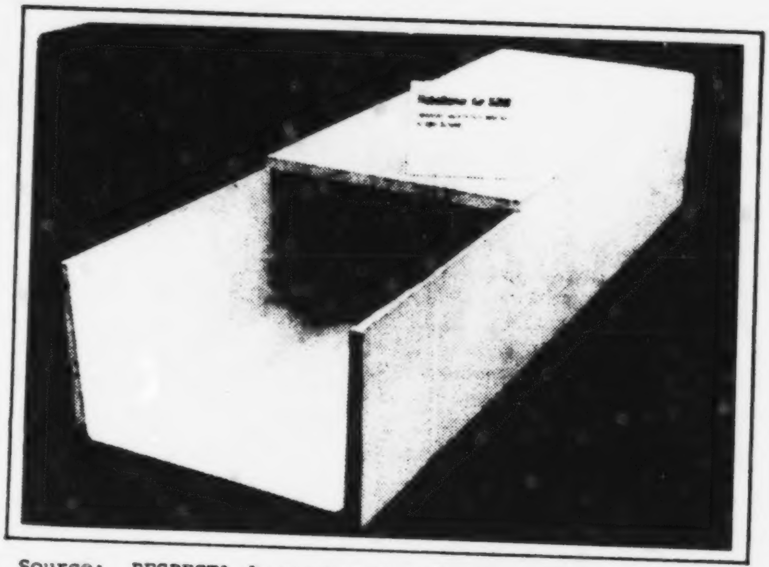
Source: CHEMIESCHUTZ documentation (Germany)

FIGURE 17: Polyester concrete window frame in four bolted sections



Source: GORENJE, VELENJE (Yugoslavia)

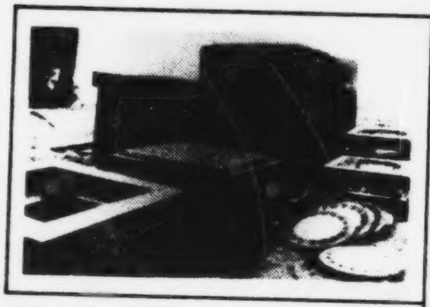
FIGURE 18: Circular coloured resin concrete window frames



Source: RESPECTA documentation (Germany)

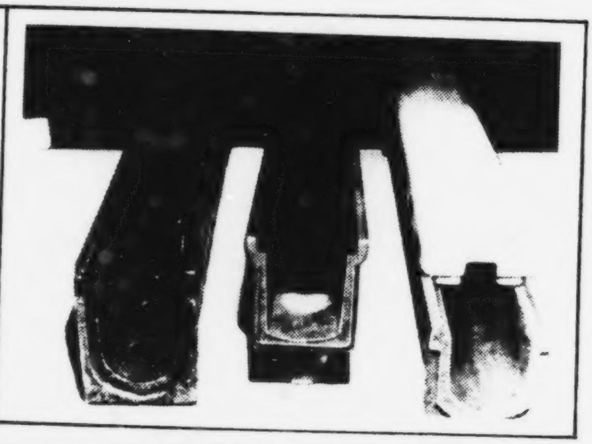
FIGURE 19: Electric wire conduit, light enough to be handled by a man (designed by the Swiss Railroad Co).

FIGURE 20: Pipe consisting of Portland cement concrete cast over a furan resin concrete core, for transporting chemical plant sewage (acid and alkali)



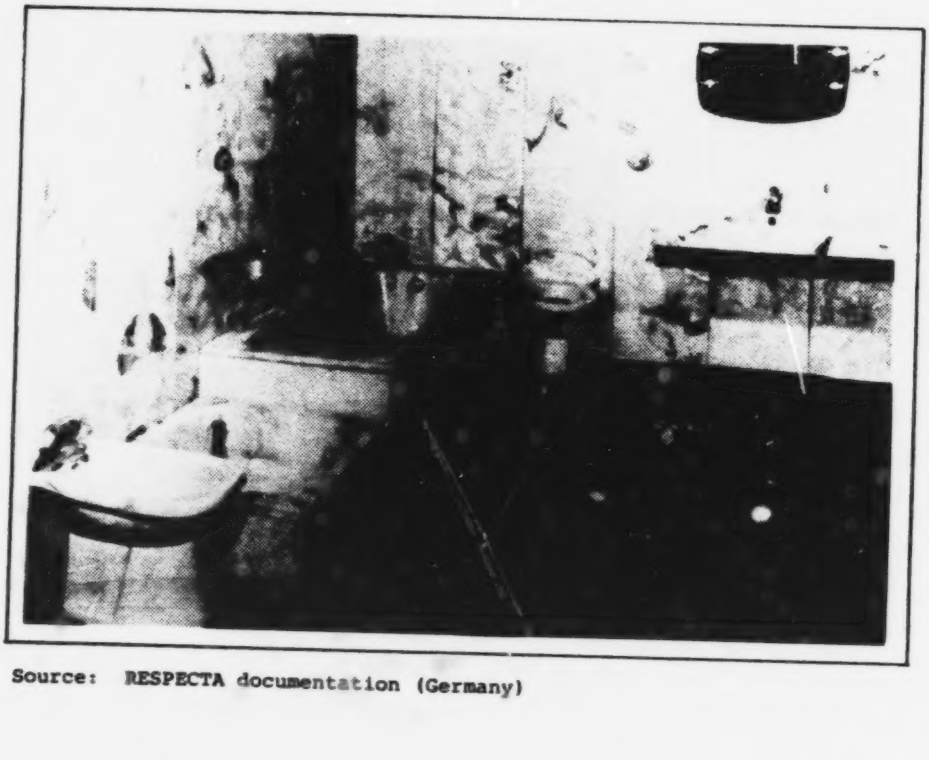
Source: BAYER AG documentation (Germany)

FIGURE 21: Sewage collectors



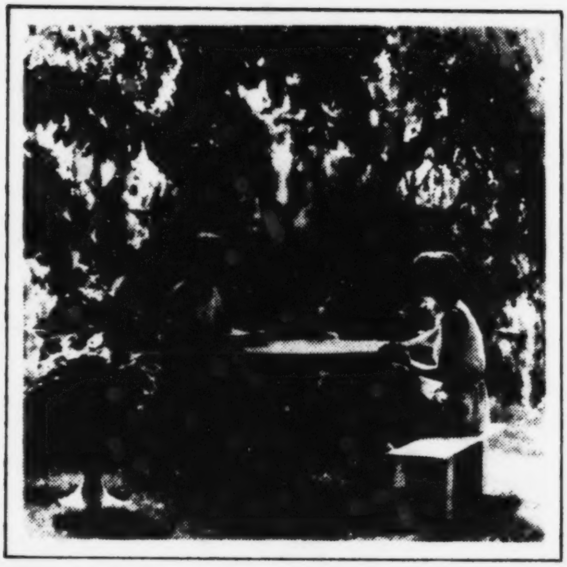
Source: BMW BETONWERKE MUNDERKINGEN GMBH, MUNDERKINGEN documentation (Germany)

FIGURE 22: Water drains



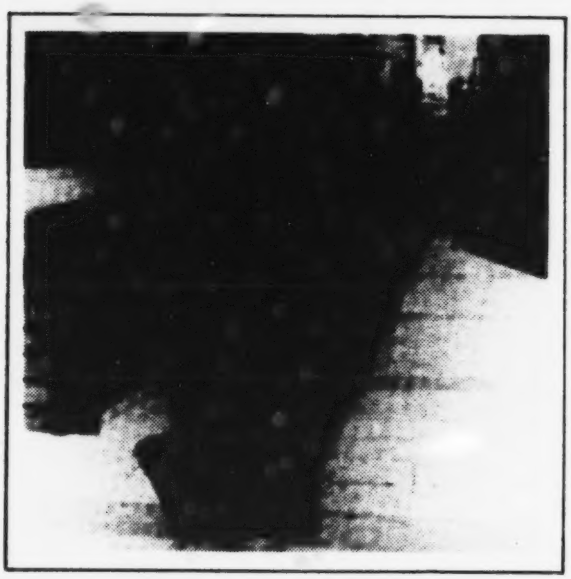
Source: RESPECTA documentation (Germany)

FIGURE 23: Synthetic marble-type resin concrete bathroom accessories (bath, shower base, sink, toilet, bidet, wall panels)



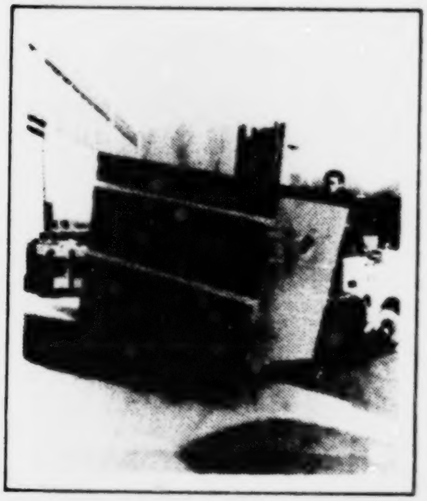
Source: INIEX documentation (Belgium)

FIGURE 24: Resin concrete garden furniture



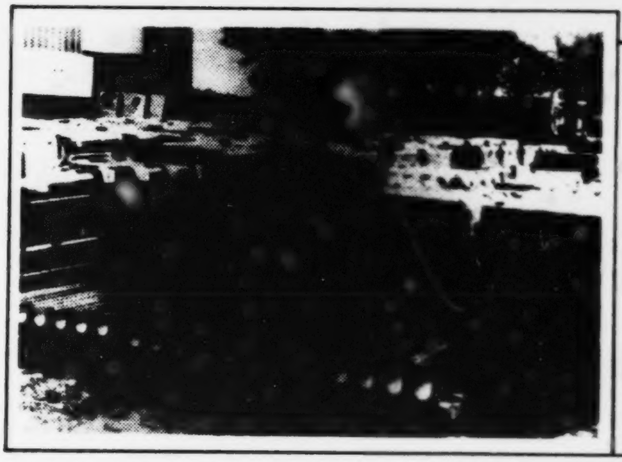
Source: INIEX documentation (Belgium)

FIGURE 25: Wastebin and pedestrian mall paving (rue du Pont Avroy in Liège)

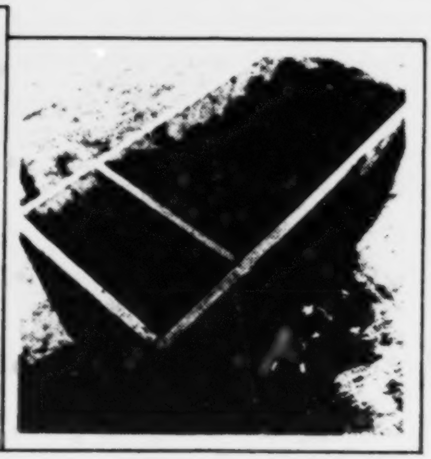


Source: WEEGELS B.V. documentation
(Netherlands)

FIGURE 26: Water/oil separator cast as a single piece (weight 1 300 kg; output 7 litres/second)



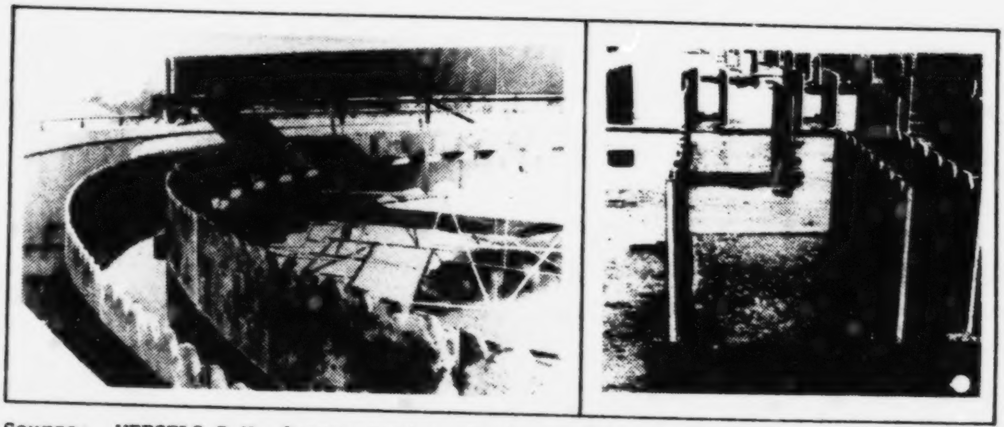
Source: RESPECTA documentation (Germany)



Source: WEEGELS B.V. documentation
(Netherlands)

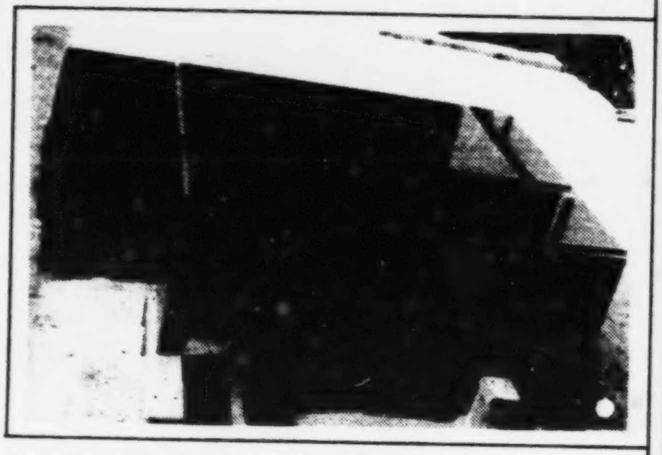
FIGURE 27: Drainage ditches

FIGURE 28: 30 m^3 container consisting of slabs bolted and glued together



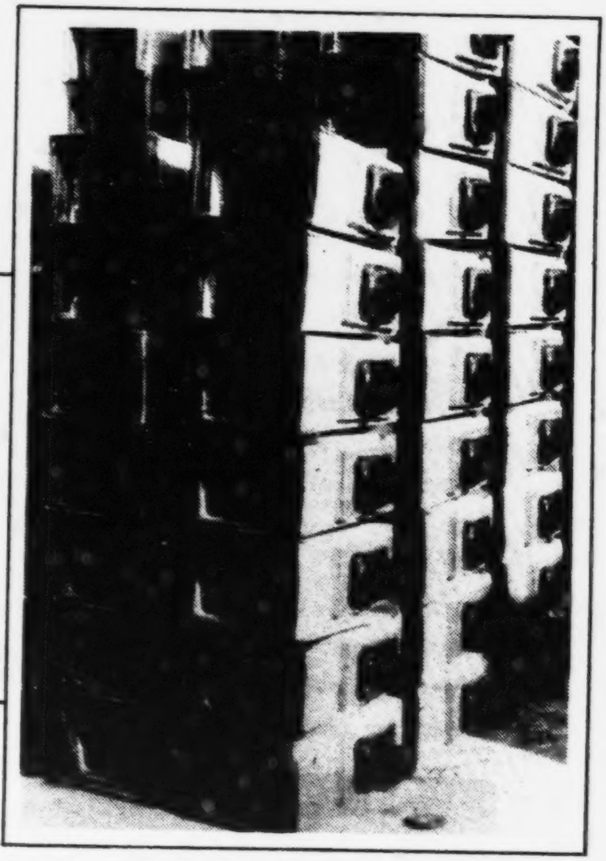
Source: WEEGELS B.V. documentation (Netherlands)

FIGURE 29: Resin concrete channels for water treatment plant



Source: WEEGELS B.V. documentation (Netherlands)

FIGURE 30: Electric transformer base (capacity 3 tonnes; size 3 x 2 x 2 metres)



Source: WEEGELS B.V. documentation (Netherlands)

FIGURE 31: Polyester concrete surface water header with metal covers and couplings embedded in the mass

5.1 Uses in Europe

The first information on the use of synthetic resin concrete dates from 1953 and comes from the United States. In Europe the development of resin concrete began in the late fifties and early sixties. (4) The past twenty years have seen the development of two main fields of application: construction and industrial products. There seems to be a greater diversity of resin concrete products in Europe than there does in the United States or Japan as indicated in Table 7.

Weegels Concrete of Weert, in the south of Holland, is one of the pioneers and a European leader in the manufacture of resin concrete products. This company started with a machine from Respecta in 1969. According to engineer Willy Hamers, who is responsible for production, the company's know-how in this field relates mainly to the construction of properly operating moulds. (11) The products manufactured by Weegels are used chiefly for the handling and treatment of sewage: drains, oil separation chambers, channels for water circulation in water treatment plants, etc.

The first Dutch water treatment plant using resin concrete channels went into operation in 1980. It had 662 channels, each with a vertical thickness of 3 cm and a horizontal thickness of 4 cm, and was only one of a series of 11 plants to be put into operation. Resin concrete was preferred over reinforced concrete, light concrete, alumininium and steel because tests demonstrated the superiority of the material in terms of freeze-thaw stability and mechanical resistance. Moreover, the weight of the channels was twice as light as that of concrete channels.

The three principal German manufacturers of gutters and drains are Aco-Drain, Anrochter Rinne and Passavant. These products are used for airports, parking lots and stadiums. Owing to the improved properties of resin concrete, the amount of friction is lower, which means that the channels can be made smaller and lighter than their counterparts are. Moreover, the hollows and swellings make it easy to use connections of varying lengths (Figure 22). Other fields of application in Germany include soundproofing systems

(BMW), prefabricated balconies (Schulte), containers for plants, pipes for wells and animal feeding troughs (Fritschi) and boundary stones (Duroplasstein). (9)

The Benelux and Japan have long, underground resin concrete pipes for telegraphic use. One third as light as the pipes formerly made of portland type concrete, they can be installed manually without the use of lifting equipment. (10)

In Switzerland, all new electric conduits used for the railways must now be manufactured in resin concrete (12) (see Figure 19).

5.1.1 Facing panels

Self-supporting facing elements probably represent the chief application of resin concrete within the construction industry. Reference 14 describes a large number of buildings throughout the world that have used these panels.

The advantages offered by resin concrete for this type of application are:

- half the weight of a comparable prefabricated concrete panel;
- an extensive array of colours and textures;
- cost saving with respect to the supporting structure (placement is easier because the material is lighter);
- increased resistance to weather conditions, freeze-thaw conditions and corrosive agents in the atmosphere;

- resistance to dirt because it can be easily washed by the rain.

As explained by Prusinski (13), the properties that the polymer concrete matrix must posses are as follows:

- sufficient rigidity to withstand handling in the plant, during transportation and on the construction site;
- maintenance of a certain degree of flexibility;
- sufficient compressive, tensile, flexural and impact strength;
- the matrix must be and remain closely bound;
- long-term resistance to thermal expansion (without cracking);
- resistance to extremes of temperature;
- capacity to be affected little, if at all, by ultra-violet rays of the sun (colour and resin);
- resistance to corrosive substances;
- impermeability and fire resistance;
- capacity to resume its original position after a load is removed, i.e. a good short and medium term "memory".

Since, for reasons of cost, panels must use a minimum amount of resin to meet these requirements, they should:

- be thin, strong and relatively light;
- possess a coefficient of expansion that is compatible with adjacent materials and the supporting material;
- be sufficiently large (e.g. 4' x 8' panels);
- be wind resistant, shockproof and earthquake-proof;
- provide other savings in the total cost of construction and maintenance costs;
- have a conventional and aesthetic appearance.

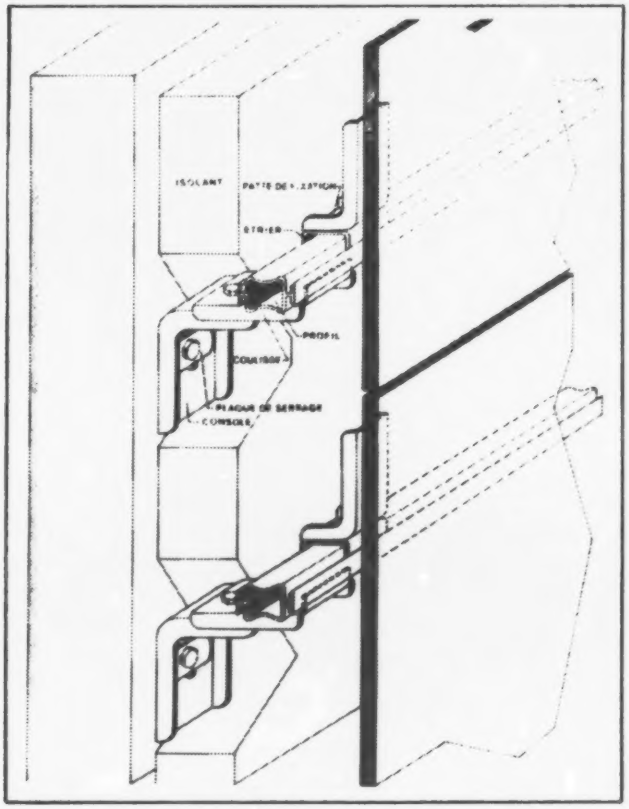
Anchorage

Resin concrete is a new material with very specific characteristics. Consequently we must avoid integrating it into a structure using traditional anchorage formulae since important data such as the coefficient of expansion must first be considered.

Through the use of simple but properly adapted anchorage systems, large resin concrete panels having variable shapes can be readily attached to a supporting structure (Figures 32, 33 and 34). These systems allow the element sufficient room for expansion and are often attached to it by screws or by a device that hooks onto metal inserts embedded in the panel. These inserts are usually placed in the mould when the mixture is poured (see Figure 12); they serve as anchors for the panel and as attachment points for other resin concrete panels.

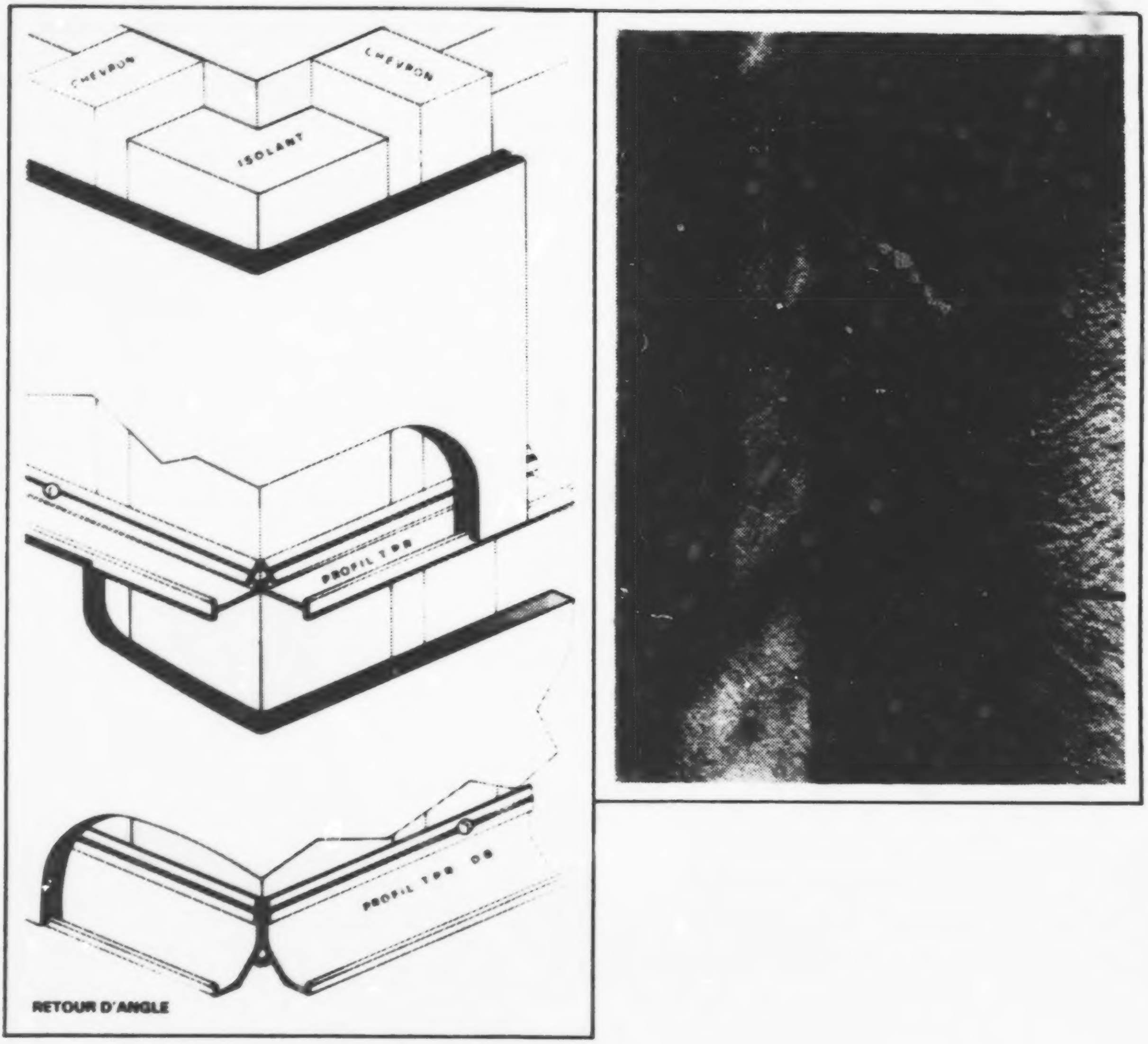
Source: INIEX documentation (Belgium)

FIGURE 32: **Anchorage systems**


ISOLANT
PATTE DE FIXATION
ETRIER
PROFIL
COULISSE
PLAQUE DE SERRAGE
CONSOLE

Source: SAFAMA ET CIE documentation (France)

FIGURE 33: **Anchorage system for panels with metal inserts embedded in the back**


CHEVRON
CHEVRON
ISOLANT
PROFIL TDB
PROFIL TDB DB
RETOUR D'ANGLE

Source: SAFAMA ET CIE documentation (France)

FIGURE 34: Anchorage System designed for attaching grooved slabs onto metal projections (example of projecting corner)

Resin concrete panels are generally cast in thicknesses no greater than a few centimetres (usually 2 cm). Although it might be feared that the presence of metal inserts might distort the product locally and require additional concrete in certain places, no pullout of the metal inserts is observed but, rather, a break is produced each time in the resin concrete itself - which attests to the perfect union between the metal insert and the material in which it is embedded. Table 8 gives the results of pullout tests conducted at 23°C and 80°C on metal inserts specially designed for resin concrete elements 2 cm thick. (1)

In cases where the load to be borne at the anchorage points is to be greater than the values expressed in Table 8, an overlay of resin concrete at those points will be allowed for in the design of the mould. Other types of metal insert will be considered in such cases. Table 9 presents the pullout values obtained with commercial metal inserts embedded in samples 5 cm thick. Once again, the break occurred in the resin concrete (RC) or even in the threaded shank (TS). The metal inserts themselves were not dislodged in any instance and freeze-thaw conditions had no effect on the pullout strength observed.

Examples of finished products

The surface finish of facing panels may resemble concrete, and this can prove advantageous in the repair of building façades (Figure 35). They often display a smooth surface (Figures 36 and 37) or successfully imitate natural stone (Figures 38 and 39) or any other finish or colour prescribed by the architect (Figures 40, 41 and 42).

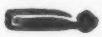
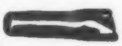
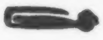
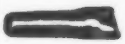
Figure 43 illustrates the stability of resin concrete both as regards its dimensions and in terms of its coloration and easy maintenance. It shows the resin concrete façade of a building on Avenue de l'Observatoire in Liège, which was constructed in 1976. After 6 years of exposure to the elements, its appearance has remained unchanged. Figure 44 shows a precast unit constituting a quarter of the complete module for housing a window. Part of the back is visible and it can be seen that the thickness of the material is constant throughout (around 2 cm) owing to the use of a matching mould during fabrication.

TABLE 8: Pullout strength of metal inserts specially designed for 2 cm thick elements (threaded cylinder welded onto a circular plate)

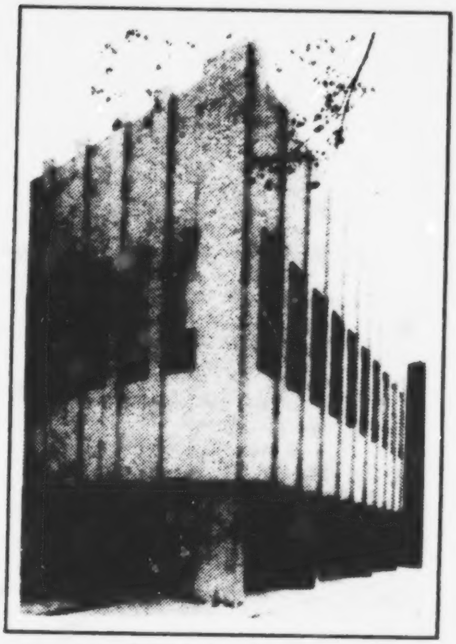
METAL INSERTS		NUMBER	PULLOUT STRENGTH (kg)	
TYPE OF THREAD	TOTAL LENGTH (mm)		23°C	80°C
M8	12	1	375	405
M8	12	2	476	541
M6	12	1	382	327
M6	12	2	482	≈600

Source: C. Michaux, INIEX, Belgium: "Les bétons de résine, applications dans le domaine de la construction": Symposium: Evolution récente des matériaux de construction, April 28-29, 1981.

TABLE 9: Pullout strenght of metal inserts embedded in 5 cm thick resin concrete plates

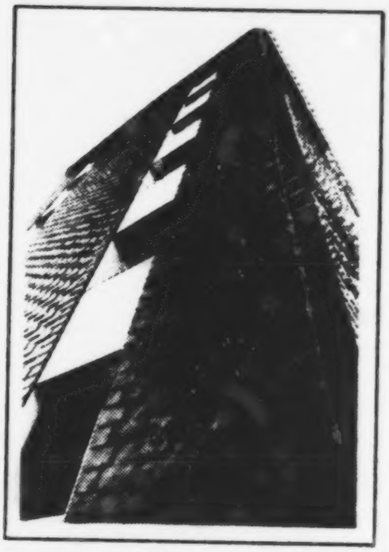
Metal inserts		Number	Pullout strength					
Type and shape	Total length (mm)		23°C	Break	50°C	Break	80°C	Break
 M 6	40	2	2065	R.C.	1840	R.C.	1363	R.C.
M 6	40	2	2168	R.C.	1922	R.C.	1744	R.C.
 M 6	40	2	1850	R.C.	1604	R.C.	1405	R.C.
M 6	35	2	1625	R.C.	1352	R.C.	1378	R.C.
 M 6	40	1	1650	R.C.	1640	R.C.	1310	R.C.
M 6	40	1	1210	T.S.	1065	T.S.	1213	T.S.
 M 8	40	1	1420	R.C.	1290	R.C.	1350	R.C.
M 6	35	1	1290	R.C.	1080	T.S.	1010	R.C.

Source: C. Michaux, INIEX, Belgium: "Les bétons de résine, applications dans le domaine de la construction": Symposium: Evolution récente des matériaux de construction, April 28-29, 1981.



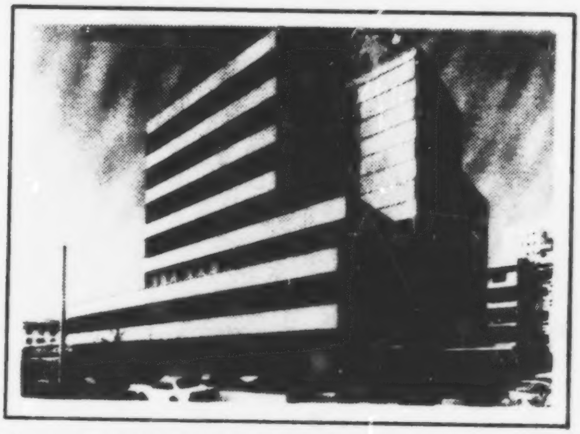
Source: PANELCRAFT B.V. documentation (Netherlands)

FIGURE 35: Restored facade with concrete - look finish



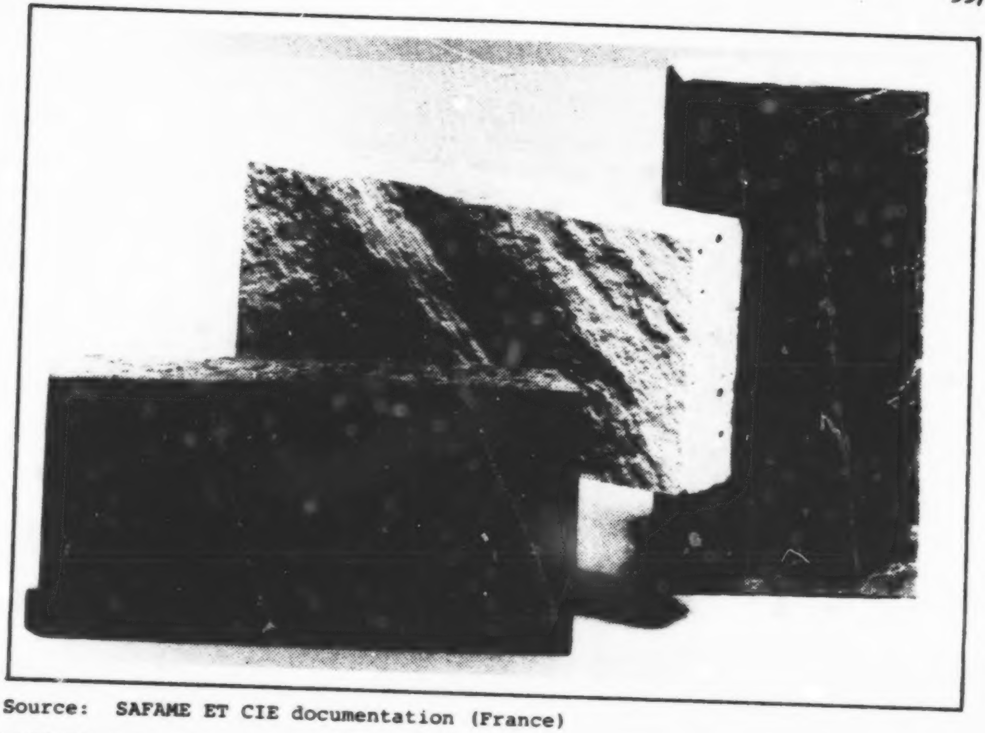
Source: SAFAMA ET CIE documentation (France)

FIGURE 36: Imbricated polyester concrete panels imitating a slate finish



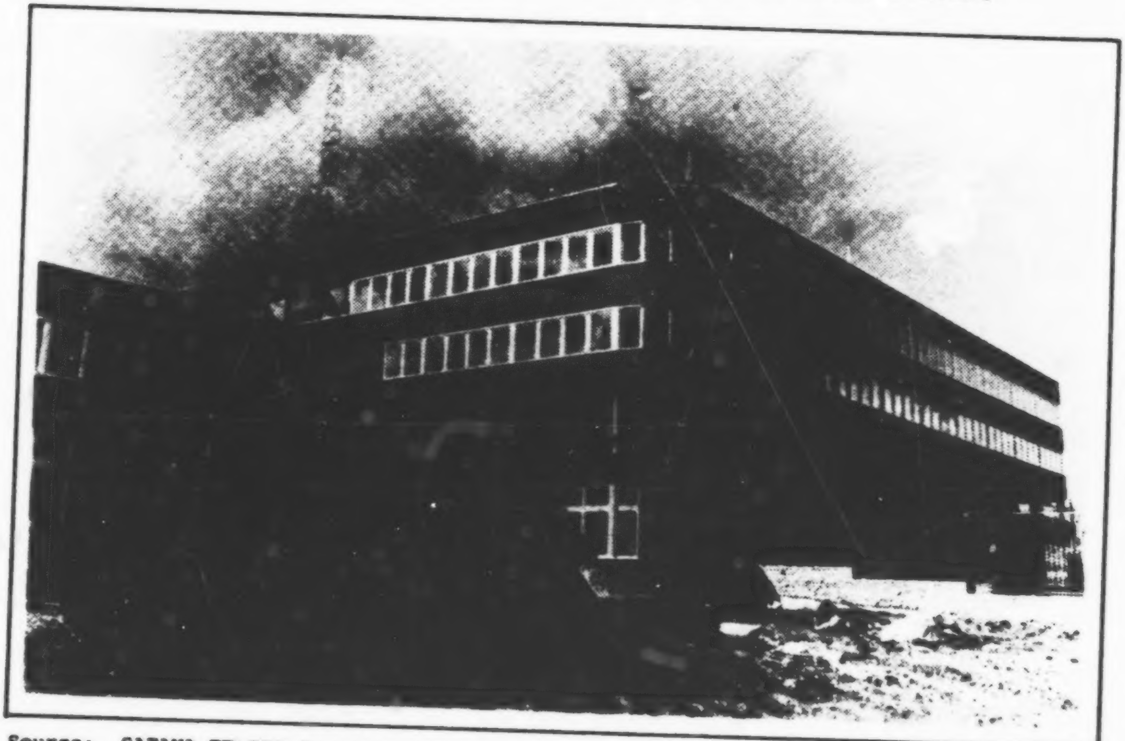
Source: PANELCRAFT B.V. documentation (Netherlands)

FIGURE 37: Smooth-finish exterior panels (Dresdner Bank, Hamburg)



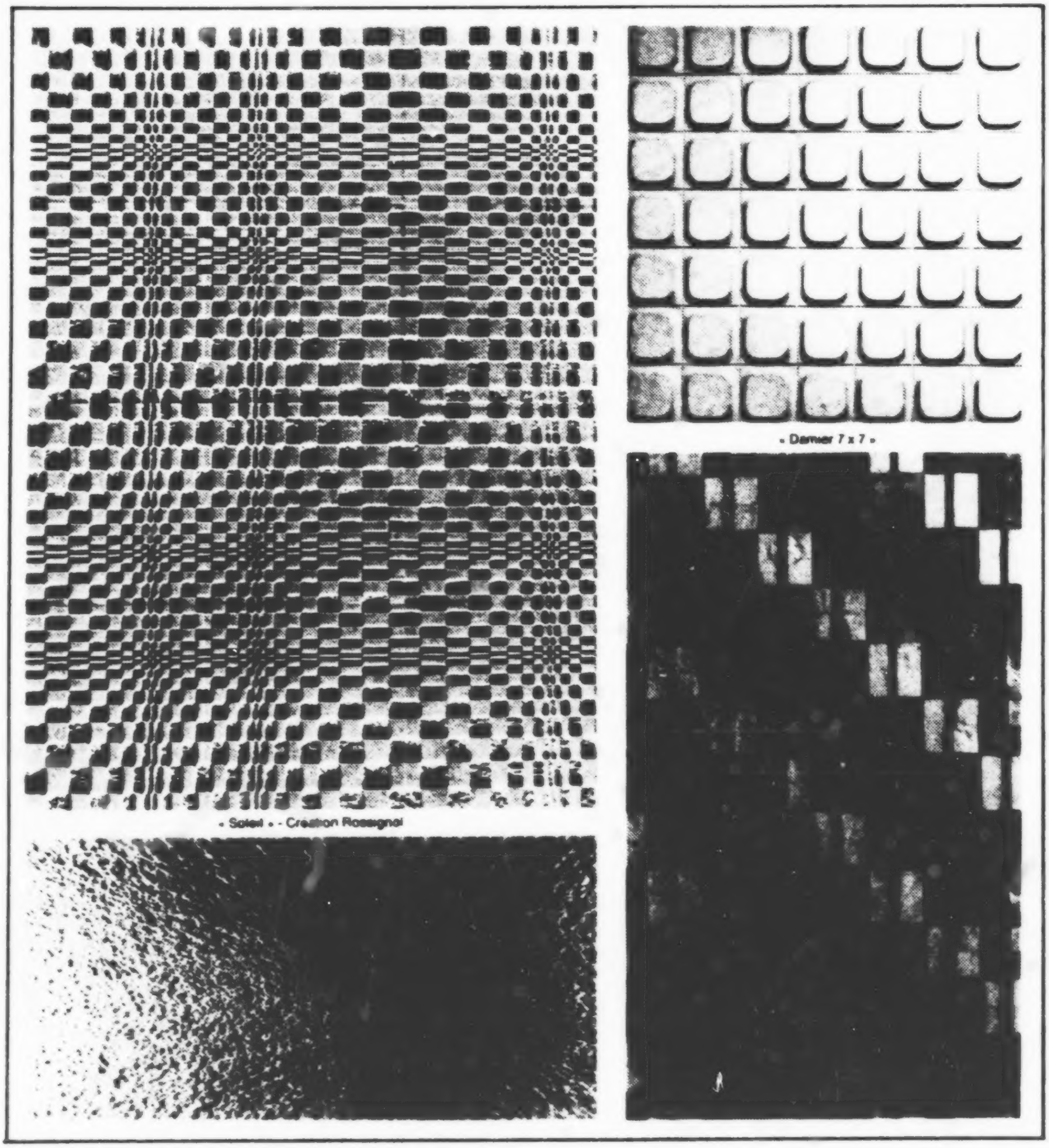
Source: SAFAME ET CIE documentation (France)

FIGURE 38: Polyester concrete panels imitating natural slate ("ARDAL")



Source: SAFAMA ET CIE documentation (France)

FIGURE 39: Polyester concrete panels imitating slate (Police Headquarters, Rennes, France)

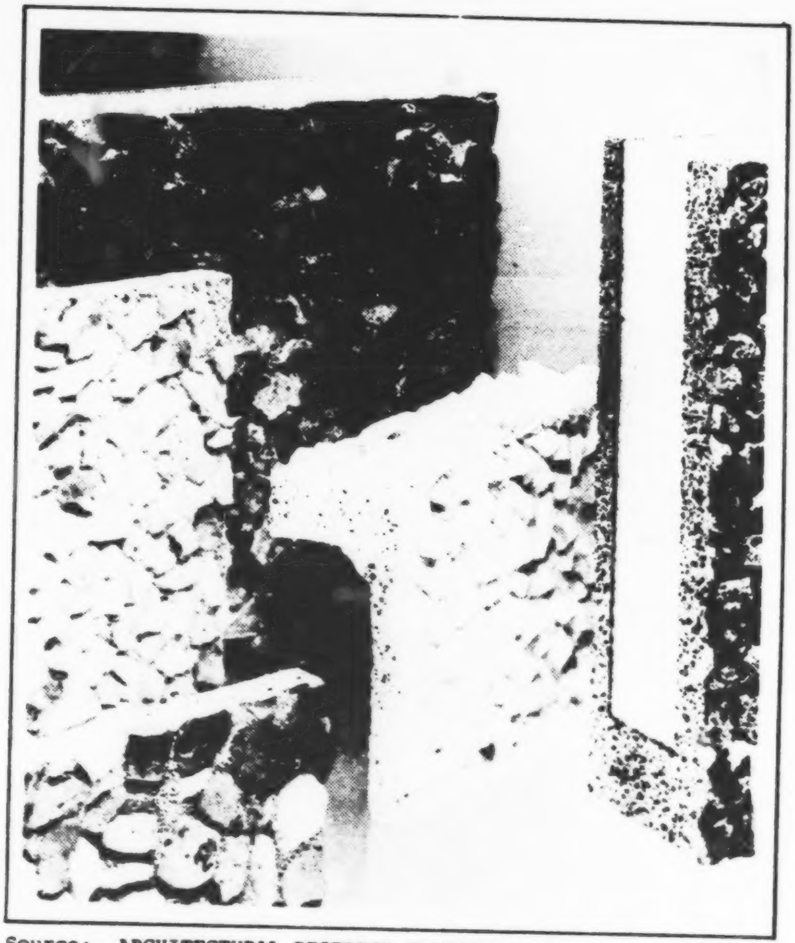


« Soleil » - Création Rossignol

« Damier 7 x 7 »

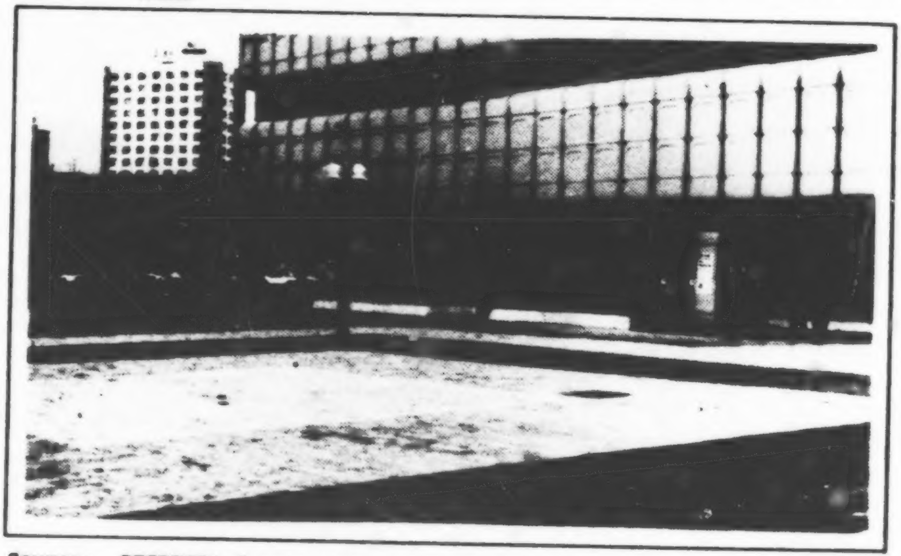
Source: SAFANA et CIE documentation (France)

FIGURE 40: Examples of ornamental resin concrete finishes



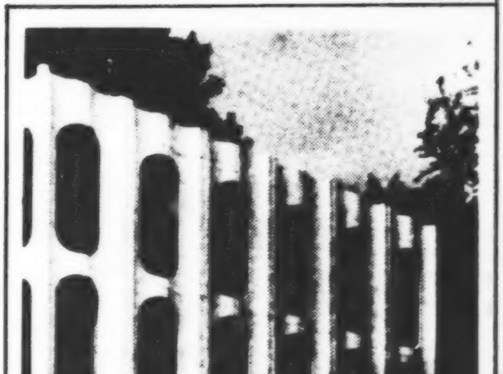
Source: ARCHITECTURAL RESEARCH CORPORATION documentation (USA)

FIGURE 41: Resin concrete-aggregate panels with insulation embedded in the mass



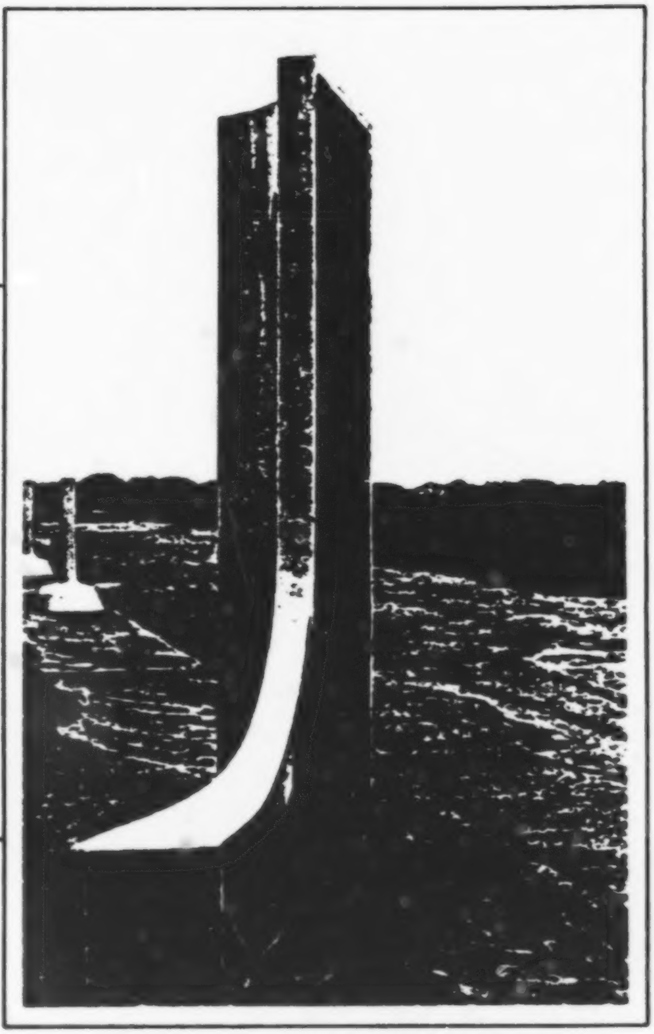
Source: RESPECTA documentation (Germany)

FIGURE 42: Resin concrete floor slabs and facing elements (plastic-look finish)



Source: INIEX documentation (Belgium)

FIGURE 43: Resin concrete façade of a building constructed in 1976 (Liège, Belgium)



Source: INIEX documentation (Belgium)

FIGURE 44: Cast element constituting a quarter of the complete module for housing a window as shown in Figure 43

The use of resin concrete panels enables savings to be made in the construction costs of the building since the panels are twice as light as equivalent concrete or granite panels. In Medias, Saudi Arabia, light prefabrication was the order of the day when full advantage was taken of the strength of resin concrete in building a palace and 200 silos. A simple levelling slab easily supported the minimum metallic structure bearing, in precise locations, the thin resin concrete elements that alone constituted a rigid ornamental exterior wall.

5.1.2 Pipes

Since 1961, polyester concrete pipes for sewage disposal have been mass produced in a similar manner to that used for cement concrete. Setting takes place in a slowly rotating mould (centrifugal casting). After over ten years' use, these pipes have proved sufficiently resistant to chemicals and sewage containing diluted acid salts and sometimes organic chemicals. The proportion of binder in these pipes is between 9 and 11% by weight. (2)

5.1.3 Expressway repair

Expressway repair through the placement of resin-based mortar was studied in the Federal Republic of Germany between 1961 and 1964. Tests conducted jointly by suppliers of polyester and polymethacrylate resin, the company Strabaq Bau-AG and the Frankfurt and Stuttgart highway administrations led to integration of the conditions for producing polyester and polymethacrylate mortars with the requirements of highway construction. (9) Laboratory research showed that polymer concrete had sufficient resistance to saline solutions, fuels, solvents, acids and diluted bases. In addition, its weathering strength corresponds to that of a good hard rock (i.e. it is higher than the level required for road construction concrete).

Besides its superior mechanical properties, its corrosion resistance in environments polluted by acids and acid salts, its very low water absorption level and its freeze-thaw stability, resin concrete has another property which makes it ideal for this type of work: its setting time is short and adjustable to the requirements of the situation (10 minutes to 2 hours). Consequently, interruption of traffic for repair work can be kept to a minimum. This rapid setting time is particularly important for the repair of expressways and other highways having dense traffic. Interchanges in particular are locations where repair time should be brief. The Army is very interested in the rapid setting potential of resin concrete for the repair of landing strips after a bombardment. In the United States, efforts to develop this type of copolymerized resin-based formulation (MMA) have resulted in setting times of 100 minutes for a temperature of -29°C and 10 minutes for 24°C. (14)

5.1.4 Earthquake-proof bridges

Utilization of the earthquake-proof properties opens up a new field of application for resin concrete. Because of a high compressive strength and a high coefficient of vibration absorption, resin concrete is a good material for bridge supports. The first earthquake-proof expressway bridge using resin concrete components was built in Germany. In addition, a team of Russian and German experts representing Bayer AG and Respecta developed specifications for this type of construction. These specifications are already in force in the USSR. (9)

5.1.5 Bridge repair

One of the major problems encountered by the authorities responsible for expressways in Canada and the United States is the deterioration of the surface of reinforced concrete bridges due to the penetration of de-icing salts and the corrosion of structural steel. The solution to this problem is the development of impermeable road surfaces that have freeze-thaw stability, wearing resistance and impact resistance. Moreover, the entire repair process must be rapid and road traffic interruption must be kept to a minimum owing to the high cost of traffic detours. Thus there is good potential here for polymer concrete.

5.1.6 Street furniture

Resin concrete lends itself well to the production of street furniture such as public benches, waste receptacles, mailboxes, sidewalk slabs, bollards, flower boxes, tables, etc. (Figure 43). The INIEX Research Centre in Belgium developed formulations using 50% recycled glass from selected refuse collections for paving a pedestrian mall in Liège and producing several hundred waste receptacles (Figure 25).

5.1.7 Art and restoration

Urban pollution, acid rain and extremes of weather are causing increasing damage to works of art and structures in certain types of stone or concrete. Art lovers and restoration experts are very interested in the potential of resin concrete in terms of design and appearance. Through the use of special techniques, complex components can be cast in a single operation.

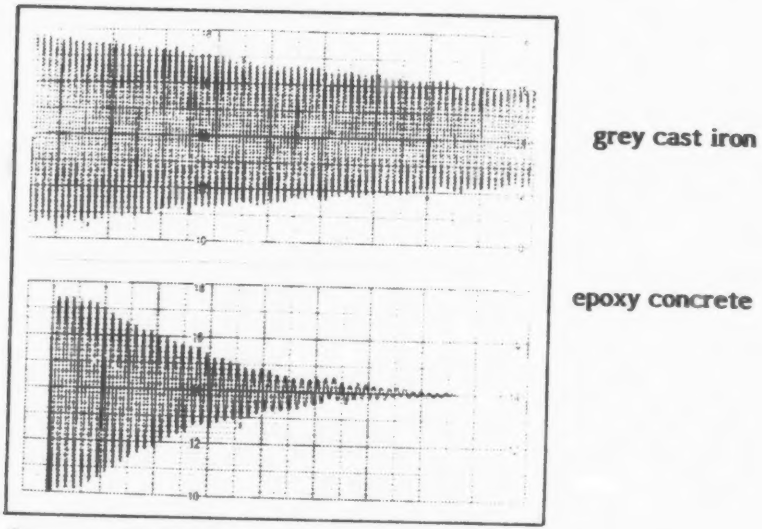
5.1.8 Machine frames

The idea of using concrete for the bases and frames of machine tools is not new. The Russians, British and Germans studied this application after the Second World War with a limited amount of success. Nevertheless, the vibration damping properties of epoxy resin concrete (see Figure 45) and the ease with which it can be cast make it perfect for this application.

A Swiss resin concrete manufacturer, the German company RESPECTA and the Swiss machine tool factory STUDER S.A. have developed a new, much cheaper technology to mass produce frames weighing tons (see Figure 46).

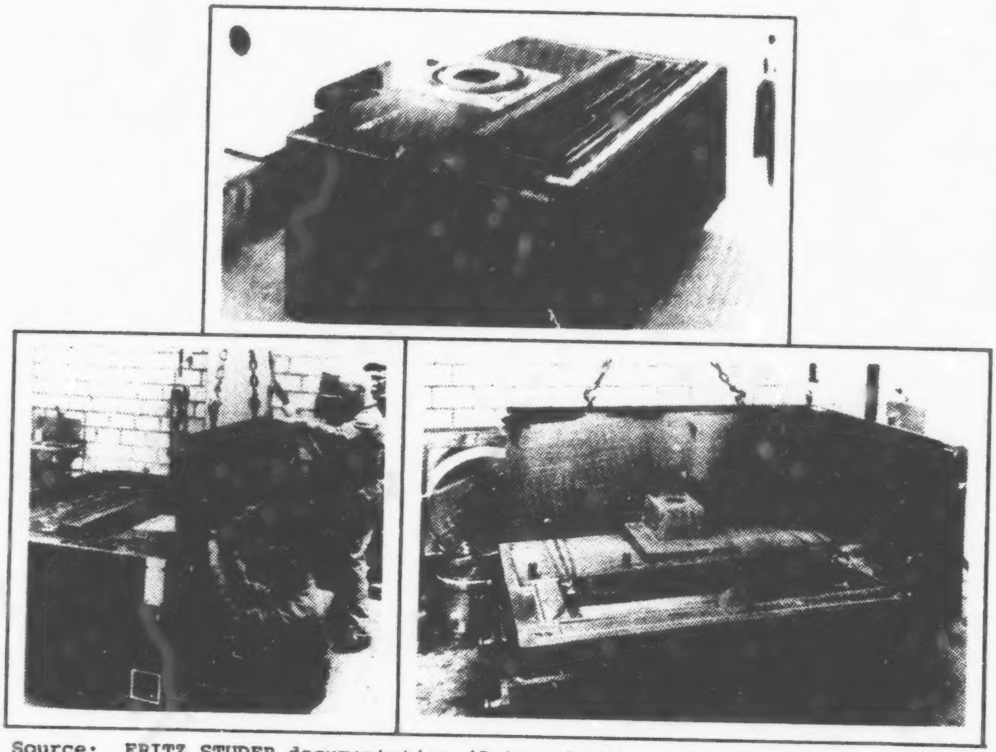
This new technology has a number of advantages (15).

- very good compressive, flexural and tensile strength;
- damping power 6 times higher than grey cast iron (see Figure 45) and 3 times higher than diabase rock



Source: FRITZ STUDER documentation (Switzerland)

FIGURE 45: Vibration damping in a grey cast iron and an epoxy concrete sample



Source: FRITZ STUDER documentation (Switzerland)

FIGURE 46: Machine frame:
a) released from the mould; b) in the process of being released;
c) partial view of the mould

frequently used for instrument panels and work tables for high precision work;

- very high dimensional accuracy;
- no measurable shrinkage;
- resistance to mineral oils;
- ability to vary the properties of epoxy concrete (i.e. the thermal expansion coefficient, the slipping characteristics, etc.);
- ability to insert or add metal pieces by gluing without having recourse to an anchorage system;
- machining reduced or eliminated;
- weight approximately 1/3 that of cast iron;
- substantially lower cost price.

5.2 Uses in Japan

The first developments in the field of resin concrete in Japan began in the fifties and the results were published in 1961. Mortar-type resin concrete is currently being used on account of its corrosion resistance and adhesive properties, e.g. as floor lining. The resins utilized for these purposes are epoxy and polyester. Unsaturated polyester resin has been used for most resin concrete structures and products in Japan because of its reasonable price and its properties which are sufficient for the majority of applications. (16 & 17)

Resin concrete is generally mixed and cast in moulds similar to those used for conventional prefabricated concrete. The percentage of resin used is generally 10% for polyester and epoxy and 20% for polyurethane resin.

Resin concrete is used for the repair and prefabrication of a variety of products. The main uses, however, seem to be in the construction industry and in the sector providing power, telephone and sewerage services.

The main prefabricated products in terms of volume of production in Japan include:

- tunnel segments for telephone cables, sewage pipes, conduits for electric wires, U-shaped gutters and covers;
- lightweight glass fibre fabric-reinforced resin mortar panels, wall panels, tiles and floor panels;
- polymer concrete columns that can compete commercially with prefabricated-concrete or steel columns.

In addition to prefabricated products, resin concrete is fabricated and cast in situ in applications such as covering for dam spillways, building foundations in a hot spring and covering for retaining dams.

Four companies produce 30 000 tonnes of resin concrete piping a year, the pipes being fabricated either by centrifugal casting of by a combined process of filament winding and extrusion. The latter process enables pipes 70 cm in diameter to be produced from a sandwich-type material including layers of glass fibre. The mechanical properties obtained are almost equivalent to those of steel (Figure 47).

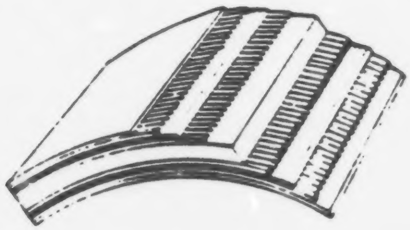


FIGURE 47: **Schematic representation of glass fibre / resin concrete / glass fibre composite pipes**

The Nippon Telephone and Telegraph Public Corporation created the first self-supporting resin concrete structures in Japan when it produced resin concrete manholes for telephone, electric, gas, ... mains. These manholes weigh only a third of their portland cement concrete counterparts. By 1977, over 40 000 resin concrete manholes had been installed, representing more than a quarter of all manholes put in place by the NTT during the period ending in that year. (18) Each of the four producing companies has a capacity of 400 units a month. In 1978, their total annual production was around 20 000 tonnes.

5.2.1 Manholes

The development of resin concrete manholes is a good illustration of the stages a product must go through to reach a point of large-scale commercialization. This is one of the cases where a new resin concrete product has succeeded in competing effectively with concrete by reason of its superior properties.

The Nippon Telephone and Telegraph Public Corporation (NTT) has been interested in the use of polymers as a structural material since 1955. Research was begun in 1960 and the first prototype was produced in 1964. Increased co-operation between the NTT researchers, the University of Kyoto and manufacturers led to the development of a commercial product in 1967. The various tests conducted between 1964 and 1971 enabled product specifications and fabrication and on-site construction techniques to be established. Mass production began in 1971 and by 1977, over 40 000 units had already been produced.

Even if resin concrete offered better mechanical properties and durability than did cement concrete, some seven years passed before resin concrete products were commercialized! The main reasons were:

- lack of data on resin concrete for product design purposes;
- no experience with polymeric materials such as binders;
- no effective reinforcement technique;

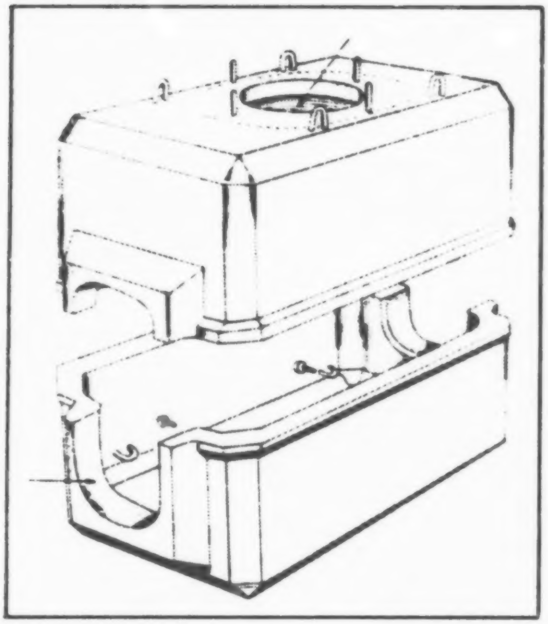


FIGURE 48: Polyester concrete manhole manufactured for the Nippon Telephone and Telegraph Public Corporation (Japan)

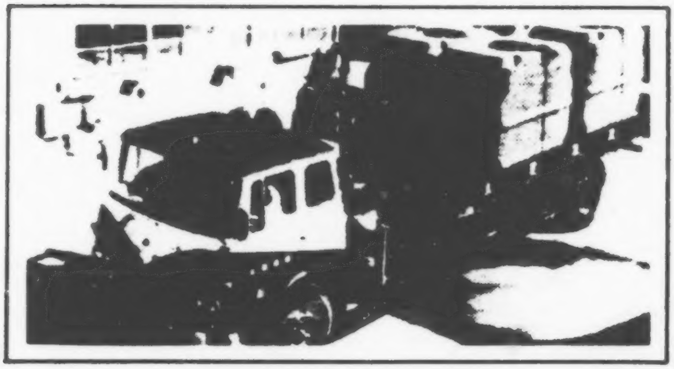


FIGURE 49: Transport of prefabricated manholes

- no studies on reinforced resin concrete;
- the high cost of resin concrete compared with portland cement concrete;
- no resin concrete production technique or equipment.

Manhole specifications

The formulation selected to meet the requirements of cost, strength and easy production with respect to manholes comprises 10,5% unsaturated polyester resin by weight with a 12% calcium carbonate filler and 77,5% aggregates less than 2 cm in diameter. The product has good fatigue strength - it resisted 2 million cycles at 60-70% of its flexural strength. Its creep modulus varies between 0,3 and 0,4. After 400 freeze-thaw cycles administered according to ASTM C290-63T, its modulus of elasticity remained unchanged. (18)

The tests showed that the mechanical strength of polymer concrete was affected little, if at all, by chemicals present in underground water but depended largely on temperature. After 10 years of soaking in saline water (pH 1.5-2.3; T = 33-55°C), samples lost about 1/4 of their flexural strength. There was negligible flexural strength loss, however, in the case of samples submerged in an outdoor tank of water. Accelerated aging tests with a "Weather-O-Meter" did not indicate any loss of mechanical strength.

Since no effective reinforcement technique has been discovered to date, resin concrete manholes are designed without reinforcement. To provide additional strength in case of accidents, however, steel rods 5 to 10 mm in diameter are used but their effect on the mechanical strength of the entire structure has not been studied.

Advantages of resin concrete for this type of application

The factors that led to the development of the product in Japan are as follows:

- The demand for telecommunications was showing sharp increases every year and the NTT was installing approximately 30 000 km of conduits and 20 000 manholes annually.

- Increasing road traffic was making it more and more difficult to carry out this work. To reduce labour costs, this work had to be as rapid and simple as possible.

For these reasons, the NTT studied techniques that would allow it gradually to abandon cast-in-situ manholes in favour of prefabricated resin concrete ones.

Studies to determine the strength, fabrication, transportation and installation effectiveness of the product led to the development of a manhole consisting of two parts that are glued together. Large manholes are built in four sections. For purposes of comparison, Table 10 shows the various weights of hydraulic concrete and resin concrete manholes.

TABLE 10: Comparative dimensions of prefabricated cement concrete and resin concrete manholes

MATERIAL	CATEGORY	INTERNAL DIMENSIONS (cm)	THICKNESS (cm)			NUMBER OF SEGMENTS	WEIGHT (tonnes)	
		LENGTH x WIDTH x HEIGHT	TOP	WALLS	BOTT.		Individual segments	Total
RESIN CONCRETE	A	100 x 100 x 150	9	5	8	2	1.1 - 1.1	2.2
	B	230 x 130 x 150	9	5	6.5	2	1.5 - 1.5	3.0
	C	300 x 140 x 170	9.5	5.5	7.5	2	2.2 - 2.2	4.4
	D	320 x 140 x 210	9.5	6.5	8.0	2	2.9 - 2.9	5.8
CEMENT CONCRETE	A	100 x 100 x 150	20	15	20	2	3.0 - 3.0	6.0
	B	230 x 130 x 150				2	3.9 - 4.4	8.3
						4	2.2 - 1.7 - 2.0 - 2.4	
	C	300 x 140 x 170				3	4.0 - 3.0 - 4.1	11.1
						6	2.1 - 1.9 - 1.2 - 1.8 - 2.3 - 1.9	
	D	320 x 140 x 210				3	4.4 - 4.1 - 4.4	13.1
						6	2.3 - 2.1 - 1.9 - 2.4 - 2.3 - 2.0	

For this type of application, resin concrete offers several advantages:

- reduction in external dimensions in the order of 20 to 30 cm;
- 1/3 to 1/2 as light as an hydraulic concrete product;
- greater transportability (can be transported in sections).

This reduction in weight and size means reduced production, storage, transportation and construction costs:

Production:

- Setting time is short. In addition, metal moulds rotate rapidly and fewer moulds are needed.
- Mechanical resistance tests can be conducted rapidly after the mixture is poured.

Storage:

- Complete hardening time is rapid so that stock can be reduced to a minimum at all times.

Transport:

- Costs are 1/4 to 1/3 less than the corresponding costs for concrete since reduced sizes and weights enable a larger number of manholes to be transported per load (Figure 49).

Constructions

- Only 30 minutes are needed to assemble the two sections of the manhole, although 90% of the prefabricated manholes are pre-assembled in the factory.

- Generally speaking, less excavation is required, and moving other underground conduits can mostly be avoided.

- Installation time is 25% of the time required for cast-in-situ manholes and 60 to 80% of the time required for prefabricated hydraulic concrete manholes.

- Resin concrete is more effective in areas where corrosive liquids are discharged and in underground areas of hot water.

5.2.2 New developments

Owing to the problems encountered with the construction of exposed tunnels in urban zones, the NTT is developing a system of producing small-diameter tunnels on the basis of quick-setting resin concrete formulations. A first version provides for the construction of 150-metre tunnel sections; the second version should produce 500-metre tunnel sections 1,2 metre in diameter at a rate of 10 metres a day.

The main feature of this system is that the walls are constructed as the tunnel is driven; quick-setting resin concrete is used (Figure 50). This application requires high mechanical resistance after a very brief setting time (see Figure 51). Reference 19 describes the work that was performed in order to obtain a very quick setting mixture.

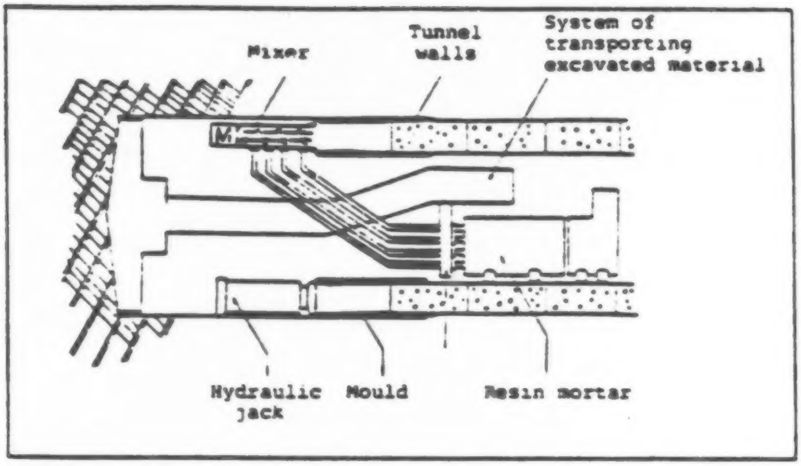

Mixer
Tunnel walls
System of transporting excavated material
M
Hydraulic jack
Mould
Resin mortar

FIGURE 50: Schematic representation of the system of continuous tunnel construction (M-II)

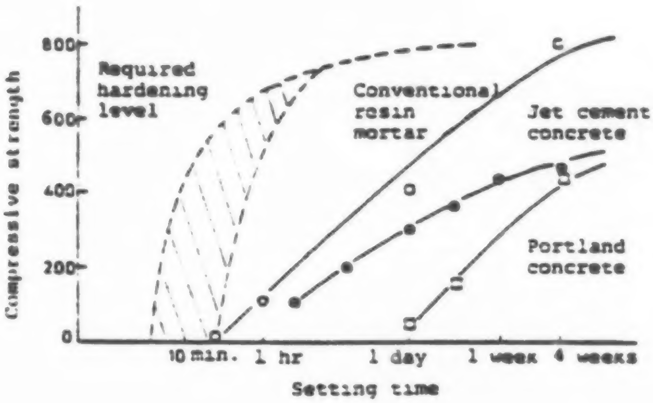


FIGURE 51: Strenght of certain construction materials in terms of setting time

Source: T. Matsuura et T. Nonaka, Nippon Telephone and Telegraph Public Corporation: "Quick Setting Resin Mortar"; Polymer in concrete, Third International Congress on polymer in concrete, KORIYAMA, Japan, May 13-15, 1981, p. 584-588.

5.3 Uses in the United States

The synthetic marble industry, consisting of over 500 enterprises, can be considered a pioneer in the development of resin concrete in the United States. Apart from the colouring agents used in synthetic marble to produce veined effects, the main difference between synthetic marble and resin concrete is the aggregate size (finer in the case of synthetic marble), and the proportion of polyester resin, which, at around 25% in the marble, is generally higher than it is in the concrete.

American manufacturers of resin concrete and synthetic marble products have been slow to use the mass casting equipment (3 to 6 machines in the USA) that is popular in Europe which has over 300 sets. This situation is probably due in part to the high cost of the quipment (85 000 $ to 300 000 $ for a RESPECTA machine with a production capacity of 20 lb to 1 100 lb/minute). A machine produced in the United States by the company Venus recently came onto market; it costs 50 000 $ and has a production capacity of 60 lb/min. According to Respecta, the production volume of most of the synthetic marble enterprises would not justify the cost of a continuous mixing machine.

The majority of the applications of resin concrete in the United States relate to the construction and civil engineering sectors. Only a dozen American enterprises are active in this field and most have previous experience in the construction or cement industry. The plastics industry has been reluctant to penetrate this market which they consider to be a sector of the concrete industry. Initially, epoxy resin and the polyester-styrene system were the most popular. The last few years, however, have seen an increase in the use of acrylic resin, especially for concrete repair.

The main uses of resin concrete in the United States fall into one of two broad categories: road and bridge repair and prefabricated products. (20, 21 & 22)

5.3.1 Road and bridge repair

The repair of concrete road surfaces and bridge decks has so far been the most common application of resin concrete in the United States. The highly developed highway system requires considerable maintenance and the number of bridges in need of repair has been estimated at over 100 000 (20). Resin concrete has proved to be a valuable material for this type of application since it is durable, strong and quick setting.

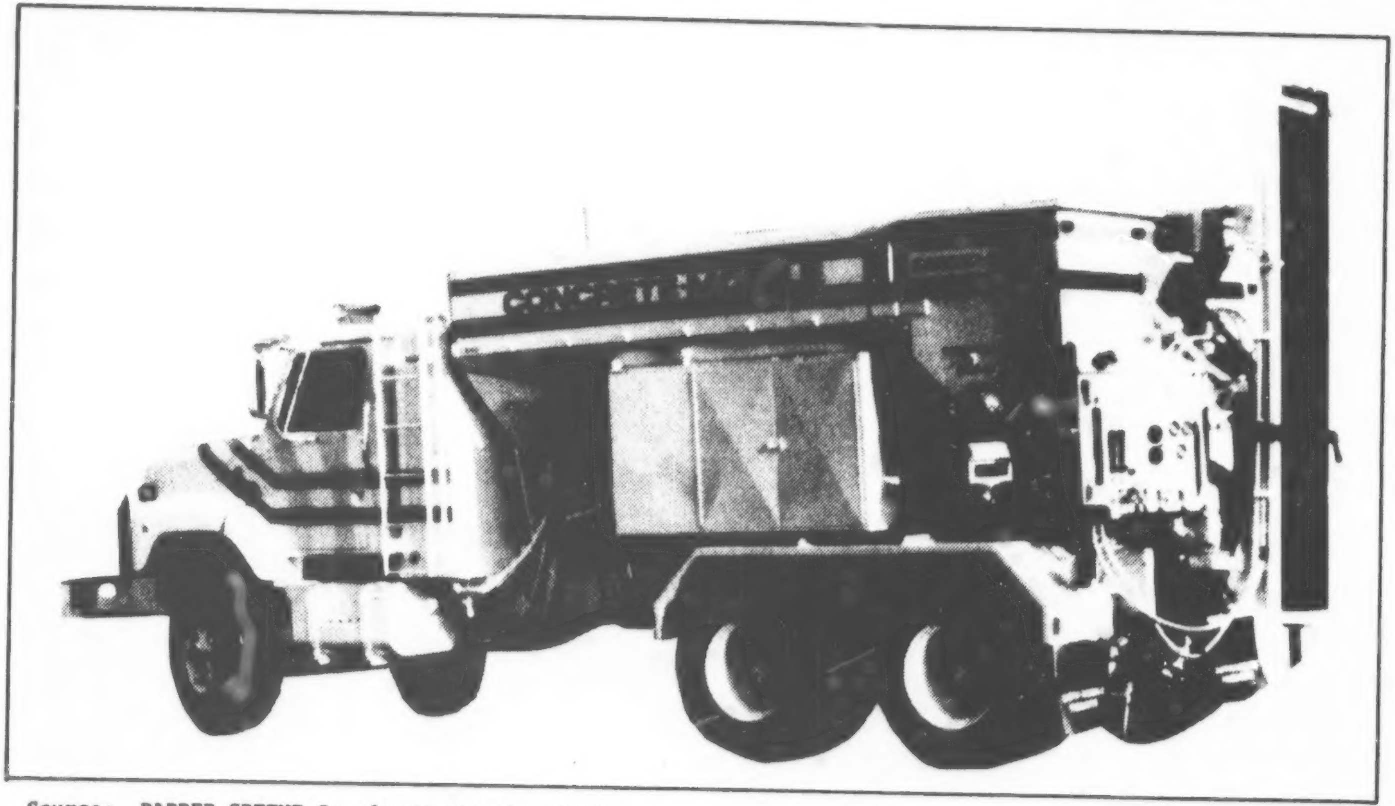
Repair of holes/potholes

Before holes can be filled with a resin concrete mixture, the damaged concrete surface and the corrosion on the reinforcing steel must first be removed. Since most resins do not tolerate water very well, the surface must be dry. For repairs larger than 7 cm, vibration of the mixture is recommended. Quite a number of bridges, highways, foundations and structures throughout the United States have been repaired in this way - generally with excellent results. (20)

In addition, the U.S. Air Force is currently financing research into methods of effecting large repairs in a wide variety of climatic conditions in a matter of hours using wet or dry aggregates. The purpose is to repair airstrips damaged by bombardments.

The results obtained so far are most encouraging: polymerization time at -20°C has been cut back to under an hour and by the incorporation of 5% by weight of steel fibre, wet aggregates containing up to 5% water can be used. The concrete produces a flexural strength of 85 kg/cm^2. The cost of materials for these special applications has been estimated at between 500 $ and 600 $/$m^3$. (23)

Through the use of a special type of continuous concrete mixer mounted on a truck (Figure 52), resin concrete can be prepared on the site a few seconds before use. This system has been successfully used for volumes of 0,75 m^3/minute and promises to be valuable for large repairs.



Source: BARBER-GREENE Co. documentation (USA)

FIGURE 52: Type of continuous concrete mixer that has been used to prepare in situ resin concrete

Road surfacing

Resin concrete surfacing was developed in the United States in order to:

- provide a layer that is impermeable to water and de-icing salt;
- repair cracked or deteriorated surfaces;
- restore road skidding resistance.

The advantages of resin concrete surfacing are: good adhesion to portland cement, a very short setting time and the fact that a thin layer is all that is required. Research has produced three application methods for road surface. (20)

The first method uses polyester-styrene as a binder and aggregates of selected gradings. A thin layer (6 mm) of the concrete to be coated is removed after which a coat of resin is applied. The resin concrete is mixed and a layer 45 mm thick is spread over the surface of the road or bridge. It is then compacted to 38 mm with the aid of asphalt rollers. Traffic can resume about 2 hours after the last placement of resin concrete.

In the second method, polyester or vinyl ester resin is used as the binder. After the surface to be coated is cleaned, dried and if necessary, repaired, a layer of monomer is applied to which a polymerization catalyst and initiator have been added. A layer of fine aggregates is spread over the monomer and compacted. After polymerization of the monomer, the process is repeated until 4 layers are obtained. The total thickness is generally between 13 and 16 mm.

The third method utilizes methyl methacrylate as the main monomer. First, wooden pegs are fixed onto the clean, dry concrete surface to act as guides for thickness. A 5 mm layer of fine aggregates having an appropriate grading is put down. Next, a 10 mm layer of aggregates is spread evenly over the surface and compacted with manual rollers. A first coat of liquid monomer is sprayed over the aggregates and, when the aggregates are completely soaked (after about 30 minutes), a more viscous solution containing 30% MMA is applied to bring about polymerization of the monomers used as binders.

5.3.2 Geothermal applications

Geothermal salt water has a very corrosive effect on most construction materials. The possibility of utilizing resin concrete to contain this hot water was demonstrated in 1972 by the Atomic Energy Commission. In 1974, the Brookhaven National Laboratory (BNL) began working on the development of resin concrete composites for this type of application. Between 1979 and 1981, Lindsey Industries of Azusa (California) using data from BNL, developed glass fibre-reinforced resin concrete pipes by filament winding which, in terms of cost and performance, were superior to comparable steel pipes used in geothermal environments. These pipes were successfully tested at 690 kPa (100 psi) and 120°C (250°F). (24)

Resin concrete made from various monomers has been used for the interior lining of steel pipes that transport hot water having temperatures of up to 220°C. In addition, the use of silica and portland cement as aggregates has enabled resin concrete to withstand 240°C temperatures. (20)

5.3.3 Prefabricated products

The prefabricated resin concrete industry is a more recent phenomenon in the United States than it is in Europe and the diversity of products is not as great. This situation is partly attributable to the lack of knowledge about the possibilities of resin concrete and the delay in adapting the European automated prefabrication techniques (25), which are more economical for large volumes of production. The main prefabricated products are structural panels (Architectural Research Corporation), corrosion-resistant floor tiles, irrigation canals, supports for electrical equipment (Polymer Concrete Research), channels for surface water drainage (Acodrain Inc.), transformer bases, underground conduits, and panels and vaults for electrical and telephone equipment (Power & Communication System Div. of Carlon, Indian Head Companies) (6, 13 & 21).

Electrical insulators

One very valuable use of resin concrete currently being developed has to do with its electrical properties. Resin concrete insulators, replacing ceramic insulators, are one of the first applications in the field of electricity. The advantages that resin concrete (polyester or methyl methacrylate) has over ceramic products are a lower price, its casting facility, facility of incorporating metal supports into the insulator, greater electrical resistance and, for insulators over 150 cm^3, an ability to withstand higher voltages (see Figures 53 & 54).

The electric Power Research Institute (EPRI) in Palo Alto, California, and the Instituto de Investigaciones Electricas in Mexico are the two principal research institutes active in the development of these applications. Over 400 high tension insulators are currently being tested in the United States and Mexico. (26)

Other applications in the electrical industry include the use of resin concrete for supports (instead of steel or wooden supports) as well as for the insulators themselves. Potential applications are electric power poles and substations, where resin concrete would have both a structural and an insulating function. (27) The Pennsylvania Power and Lights Company is currently building a 12 kV substation using cast-in-situ resin concrete. (28)

EPRI and the Florida Power and Lights Company are jointly developing resin concrete electric power poles, which, while being less costly than conventional power poles, will not require ceramic insulators either. Besides being used for rapid repair work in electric power plants, resin concrete has other major potential. EPRI and the Bonneville Power Administration, for example, are testing it as insulation for a 230 kV high tension underground power line. (27) This could mean a major reduction in the cost of constructing underground power lines in urban environments.

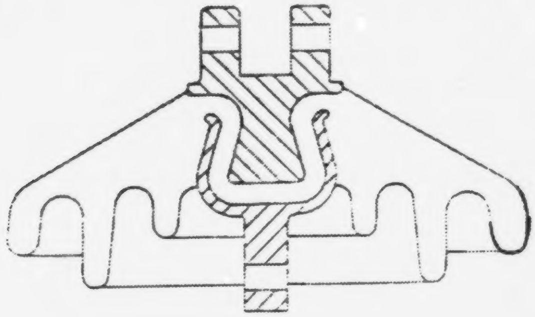


FIGURE 53: Schematic drawing of a suspension insulator developed by the Electric Power Research Institute of California

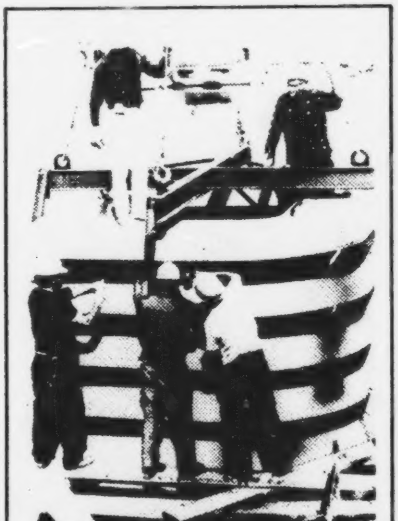


FIGURE 54: Installation of a high tension resin concrete insulator in the United States

6.0 POLYMER-IMPREGNATED CONCRETE

6.1 Introduction

Portland cement concrete is a material riddled with interconnected or partially isolated cavities and capillaries. The existence of these capillaries is the result of the fact that manufacture of the concrete requires a considerably greater quantity of water than the quantity strictly necessary for hydrating the cement. After hardening, there is a certain volume of excess water that did not form any chemical combinations and is eventually eliminated from the concrete at a rate that depends on curing conditions. Thus a network of capillaries is formed in which water and air are in a state of equilibrium.

The concrete's impermeability, its freeze-thaw durability and its corrosion resistance are closely associated with the number of pores in its mass. These pores are therefore a determining factor in the concrete's durability: the more numerous the pores, the faster and the more serious the degradation of the concrete. By filling the accessible voids in the concrete with polymers, we can greatly increase the concrete's resistance to degradation, its compressive strength, its tensile strenght, its wearing resistance and its impact strength. In addition, the effects of stress concentrated in the concrete's microcracks are reduced, which in turn improves its mechanical strength.

Impregnation is carried out by introducing into the pores of the concrete a low-viscosity liquid monomer or polymer which is hardened in situ. When most of the water in the concrete has been eliminated through drying, up to 90% of the pores can be filled with polymers.

The first work on polymer concrete centred mainly on complete impregnation of the concrete; subsequently the focus shifted to surface impregnation. None of the current applications in the United States uses complete impregnation. (20)

6.2 History

The first work on concrete impregnation was performed by the Brookhaven National Laboratory and the Bureau of Reclamation (now the US Water and Power Resources Services) and published in 1968. (29) This work generated interest from research groups around the world, who began to study the subject. The countries concerned were Japan (1967), the USSR (1970), Britain, Canada (1974) and Italy.

Until the mid-seventies most of the research on the use of polymers in concrete centred on impregnated concrete. Since then, however, interest in resin concrete has grown and impregnated concrete has received somewhat less attention.

6.3 Raw materials

6.3.1 Concrete

All types of aggregates, cements and additives can be used to prepare polymer-impregnated concrete (PIC). Moreover, the maturation procedure chosen to obtain optimal strength is not critical, although the final properties of the impregnated concrete will vary somewhat according to the type of concrete used. A dense concrete would seem preferable and would require a smaller quantity of polymers for impregnation purposes than would cellular concrete. (30)

6.3.2 Monomer

The selection of an appropriate monomer for impregnation will be based on its viscosity, cost, availability and volatility and the desired final properties of the impregnated concrete such as depth of impregnation. Most of the experiments conducted have used MMA or vinyl-type monomers. The properties of the most common monomers used for concrete impregnation are listed in Table 11. Table 12 gives the typical mechanical properties of impregnated concrete according to the monomer used.

TABLE II: Physical properties of monomers used in polymer-impregnated concrete

Monomer	Viscosity (centipoises)	Density (g/cm^3)	Steam pressure (mm Hg)	Boiling point (°C)	Water solubility (%)
Acrylonitrile	0.34$^{(3)}$	0.81	85.0 $^{(2)}$	77	7.4$^{(3)}$
Diallyl Phthalate	12.0 $^{(2)}$	-	2.54$^{(6)}$	300	Insol.
Methyl methacrylate	0.57$^{(3)}$	0.94	35.0 $^{(2)}$	100	1.5$^{(4)}$
Monochlorostyrene	1.04$^{(3)}$	1.11	0.68$^{(2)}$	180	0.0064$^{(3)}$
Styrene	0.76$^{(2)}$	0.91	2.9 $^{(2)}$	135	0.070$^{(3)}$
T-butyl styrene	1.46$^{(3)}$	0.88	1.0 $^{(5)}$	218	0.0005$^{(3)}$
Vinyl acetate	0.43$^{(2)}$	0.93	115.0 $^{(3)}$	73	2.5$^{(2)}$
Vinyl Chloride	0.28$^{(1)}$	0.91	1660.0 $^{(2)}$	-13.9	Weak
Vinylidene chloride	--	1.21	599.0 $^{(3)}$	32	Insol.

(1) -20°C (2) 20°C (3) 25°C (4) 30°C (5) 46°C (6) 150°C

Source: American Concrete Institute, Committe 548; «Polymers in Concrete», Détroit, Michigan, USA, 1977, 92 pages, p. 54.

TABLE 12: Typical mechanical properties of polymer-impregnated concrete (concrete dried at 105°C overnight, radiation polymerization)

Polymer	Polymer loading (wt %)	Resistance (MPa)			Modulus (10^4 MPa)	
		Compressive	Tensile	Flexural	Uniaxial test	Beam test
Unimpregnated	0	35	2	4	1.9	2.1
MMA	4.6-6.7	142	11	18	4.4	4.3
MMA + 10% TMPTMA	5.5-7.6	151	11	15	4.3	4.3
Styrene	4.2-6.0	99	8	16	4.4	4.4
Acrylonitrile	3.2-6.0	99	7	10	4.1	3.2
Chlorostyrene	4.9-6.9	113	8	17	3.9	4.4
10% Polyester + 90% Styrene	6.3-7.4	144	11	23	4.6	4.5
Vinyl chloride*	3.0-5.0	72	5	--	2.9	--
Vinylidine chloride*	1.5-2.8	47	3	--	2.1	--
t-Butyl styrene*	5.3-6.0	127	10	--	4.5	--
60% styrene + 40% MPTMA*	5.9-7.3	120	6	--	4.4	--

Note: * Dried at 150°C overnight.

Source: J.T. Dikeou, "Development and Use of Polymer Concrete and Polymer Impregnated Concrete"; Progress in Concrete Technology, Ed. V.M. Malhotra, CANMET, Ottawa, 1980, pp 539-582.

Most glassy polymers have a tensile strength between 34 and 68 MPa, a compressive strength between 75 and 130 MPa and a modulus of elasticity of 690 MPa. Thermal decomposition of these polymers takes place at around 200°C, except for MMA, which decomposes at 260°C. (22)

Prefabricated products can be impregnated with viscous monomers (over 20 centipoises). Generally speaking, it is useful, however, to reduce their viscosity by mixing them with a low-viscosity comonomer such as MMA. (24 & 30) Copolymerization through the use of an appropriate bifunctional or polyfunctional monomer increases the polymer's mechanical, chemical and thermal resistance. The increase depends on the degree of cross-linking in the polymer. TMPTMA is a cross-linking agent frequently used with vinyl monomers such as MMA and styrene.

6.3.3 Polymerization

Three methods are currently used in polymerization by free radicals:

- A compound (catalyst) which decomposes into free radicals is added to the monomer: this is the thermal-catalytic method.
- The catalyst may also be decomposed by polymerization promotors or accelerators, in which case polymerization begins immediately upon addition of the promotor. This technique is reserved for surface impregnation.
- Free radicals may also be produced through the use of ionizing radiation such as that emitted by a radioactive source of cobalt-60.

The mechanical properties of the impregnated concrete vary according to polymerization method, particularly in the case of MMA (see Table 13). The thermal-catalytic method is the most practical and the most popular. It can be applied to large specimens and its rapid rate of polymerization is a great asset. (22) The use of monomers containing an initiator does however require adequate safety precautions during storage and handling (ventilation, avoiding proximity to flames, etc.)

6.4 Properties

The mechanical properties and durability of PIC are greatly affected by the proportion of the cement pores filled with polymers and by the type of monomer used. (30) To obtain optimal properties, most of the water must be removed from the concrete prior to impregnation, thus creating maximum porosity. The ideal drying temperature is around 150°C. This temperature gives a fairly fast drying rate without seriously altering the concrete's strength. In the case of large products, strict temperature and drying rate control may be necessary to avoid cracking in the concrete.

Impregnation considerably increases freeze-thaw stability and also improves chemical resistance, though in a less dramatic way (see Table 14). Other effects include increases of around 30% in the thermal coefficient of expansion and 13% in thermal diffusivity and a specific heat reduction of 17%. (31)

In the case of impregnation with MMA and other glassy polymers, many researchers have noted an increase in abrasion resistance, Young's modulus and compressive, tensile and impact strength. (31)

From the very first, PIC has been regarded as a material with a high level of mechanical strength and very good resistance to degradation both of the concrete and of the reinforcing steel. Applications have sought to take

TABLE 13: **Effect of polymerization methods on strength or polymer-impregnated concrete**

POLYMER	FORCE (PSI)					
	Compression		Tension		Flexion	
	R.	T.	R.	T.	R.	T.
Control	4,950	5,260	335	388	632	665
MMA	20,620	18,160	1,630	1,510	2,640	2,290
MMA + 10% TMPTMA	21,950	19,000	1,510	1,250	2,200	---
Styrene	14,140	8,790	1,100	720	2,300	1,060
Chlorostyrene	16,090	14,390	1,120	1,200	2,380	1,580
Acrylonitrile	14,410	10,750	1,040	870	1,470	620

R: Radiation
T: Thermal-catalytic

Source: American Concrete Institute, Committee 548, «Polymers in Concrete»; Detroit, Michigan, USA, 1977, p 47.

TABLE 14: Durability of concrete impregnated with type of various monomer (thermal-catalytically cured; dried at 105°C prior to impregnation)

PROPERTY	CONTROL Undried	 Dried	MMA	STYRENE	MMA +10% THPTMA	ACRYLONITRILE	CHLOROSTYRENE
Freeze-thaw							
No. of cycles	740	440	3,650	5,440	4,660	4,120	1,800
% weight loss	25	28	2	21	0	6	10
Sulphate attack							
No. of days	480	605	720	690	630	540	300
% weight loss	0,466	0,522	0,006	0,030	0,003	0,032	0,009
Acid resistance (15% HCl)							
No. of days	105	106	805	8-5	709	621	292
% weight loss	27	26	9	12	7	12	8
Acid resistance (15% H_2SO_4)							
No. of days	49	77	119	77	--	70	77
% weight loss	35	30	26	29	--	31	26
Abrasion loss							
Inches	0,050	0,036	0,015	0,037	0,019	0,026	--
Weight loss (g)	14	7	4	6	5	6	--
Cavitation (2 hr exposure)							
Inches	0,320	0,262	0,020	0,009	--	0,092	0,115

Source: American Concrete Institute, Committee 548, "Polymers in Concrete"; Detroit, Michigan, USA, 1977, 92 pages p. 54.

advantage of these properties. Its main limitation is the cost of the monomer (31) when more than one surface has to be impregnated. In addition, the procedure is relatively long and complicated, resulting in high labour costs.

6.5 Preparation

Concrete may be either fully impregnated or, if the desired effect is increased freeze-thaw durability rather than improved mechanical resistance, superficially impregnated.

6.5.1 Full impregnation

Experiments have shown that several process parameters have an effect on the strength of fully impregnated concrete. These are the degree of dryness and vacuum, soak pressure and soak time. Excellent results were obtained when dense concrete products were impregnated to a depth of 30 cm using the following method:

- Dry to constant weight at 150°C. Dryness should be achieved in approximately 24 hours.
- Put under vacuum for about 30 minutes.
- Introduce monomer under vacuum and pressurize to 170 kPa. Pressure-soak for approximately 60 minutes (absolute pressure).
- Place concrete section under water to reduce monomer loss. Polymerize in situ with hot water, steam or even radiation.

6.5.2 Partial impregnation

Soaking unevacuated samples results in partial impregnation of the concrete and hence a somewhat lower strength. In general, overnight soaking of small, dry concrete specimens in MMA will result in filling 70 to 80% of the voids that can be filled when the concrete is first evacuated. Mechanical strength will be increased from 34,5 MPa to around 110 MPa. (30)

Partial impregnation can take place by complete immersion in monomer or by the application of monomer to just one surface. The depth of impregnation depends on the pressure applied, the soak time and the viscosity of the monomer. Atmospheric soaking with low viscosity monomers has produced impregnation depths of several inches. The use of higher viscosity monomers results in a more uniform depth of penetration, but pressure would be required.

In the United States, PIC applications involve the partial impregnation method. Bridge deck impregnation to a depth of 4 cm is a major application. The procedure is as follows: (20)

- The surface must be cleared of contaminants such as grease, oil, etc.
- The surface must be dried for 6 to 8 hours at a surface temperature of 120 to 150°C. To minimize variations of temperature inside the concrete, the surface to be dried is covered with 1 cm of sand.
- The dry concrete surface is cooled down to at least 30°C.
- The monomer is applied onto the sand 3 to 5 kg per m^2. The sand holds the monomer during the soaking period, which lasts 4 to 6 hours, and the entire surface is covered with a plastic sheet. The composition recommended in the United States is:

MMA 95%, TMPTMA 5%, isobutyronitrile (initiator) 0,5 to 1%.

- The monomer is polymerized by heating to between 65 and 90°C for 2 to 4 hours with low pressure steam. Flames and other direct sources of strong heat should be avoided since the monomer gases might catch fire.

6.6 Uses in the United States

In the United States, partial concrete impregnation is used for the protection of bridges, concrete structures and buildings. The monomer most commonly used is MMA. Some twenty bridge decks have been impregnated to date and some of these applications are described in reference 32. With one exception, the bridges were new and the intention was to protect them from penetration by de-icing salt and thus avoid corrosion of the steel reinforcing. The feasibility of bridge deck impregnation has been demonstrated.(31)

The Federal Highway Administration which has been interested in bridge deck impregnation since 1974, subsidizes research aimed at developing impregnation methods that do not require heating of the concrete for drying or hardening purposes. If the research is successful, the main drawback of current impregnation technology can be eliminated.

Surface impregnation of spillways and artificial lakes at the Bworssaka Dam in Idaho and the Lippy Dam in Montana has enabled these dams to be restored.(22)

Deteriorated building structures have been repaired by monomer impregnation. The ceiling slabs in Cass County Prison, North Dakota, for instance, had deteriorated considerably and mechanical strength was restored by MMA impregnation.

Prestressed concrete columns for bridges is also a very good potential market for PIC on account of their excellent structural property and their durability in these applications. (32)

PIC has also been considered for a number of other applications as well, including prefabricated tunnel sections, pipes, supports for mine galleries, railway sleepers, tanks for seawater desalination plants, boats, curbstones and sinks.

Research conducted in the United States on impregnation of post-tensioned beams indicates that flexural strength can be substantially increased by the use of up to 4 times more stressing cable than that required for normal concrete. The mechanical strength and increased durability offers great potential for beams used in a hostile environment.

6.7 Uses in Japan

Fundamental research on PIC began in Japan in 1967. A good number of research organizations and some companies contributed. In 1977, the Japan PIC Company was founded for the exclusive manufacture of PIC products. The chief monomers used for concrete impregnation in Japan are styrene and MMA.

Only a few companies are currently manufacturing PIC products. The products that have been developed include pump bases for sulphuric acid plants, window frames for an underwater restaurant, various types of panels, anti-corrosion frames (using extruded asbestos products), covers for electric-wire conduits, heating tiles, pavement for a new bus transport system, floating cylinders for drilling platforms and numerous conduits for electric cables. (17)

Current research has led to the manufacture of impregnated pipes in less than 30 hours without the aid of an autoclave or drying ovens. (33) The use of PIC pipes for gas pipelines has been studied in China by means of an experimental gas pipeline, and results indicate that the pipes satisfy the specifications for use at 15 atmospheres. (34)

The Japanese have developed a new type of impregnated composite called Gypsum-Polymer Composite (GPC). This product has been used for patio tables, statues, street lamps, bathroom counters and panels. The intention was to replace cement with a binder having less energy content and to utilize an inexpensive waste material. The product is made from gypsum obtained through chimney gas purification by a large number of Japanese thermal power stations. Impregnation greatly enhances mechanical strength and resistance to weather conditions. The properties and process technology of GPC are discussed in references 35 and 36.

Many PIC products have been developed to date by many different institutions and companies in Japan. These products do not enjoy a large distribution, however, and commercialization is difficult because of a cost/performance rating that does not favour the applications intended. Recently, increased interest was shown in Japan in the development of in situ impregnation applications such as roof decks, floors, dam spillway lining, etc.

6.7.1 Other applications

In India a research programme sponsored by UNIDO is aimed specifically at the development of pipes and storage tanks. An application contemplated in Italy is the use of PIC to store radioactive waste. (37)

7.0 POLYMER-PORTLAND CEMENT CONCRETE

7.1 Definition

Polymer portland Cement Concrete (PPCC) - also known as Polymer Cement Concrete (PCC) - is produced by adding a monomer or polymer to a fresh portland cement concrete mixture which is then placed in the conventional manner. Polymerization or, in the case of latexes, the formation of films takes place after the concrete has been placed. This procedure makes it very easy to incorporate polymer into the concrete but improvement of the properties is not as great as it is with PIC or PC.

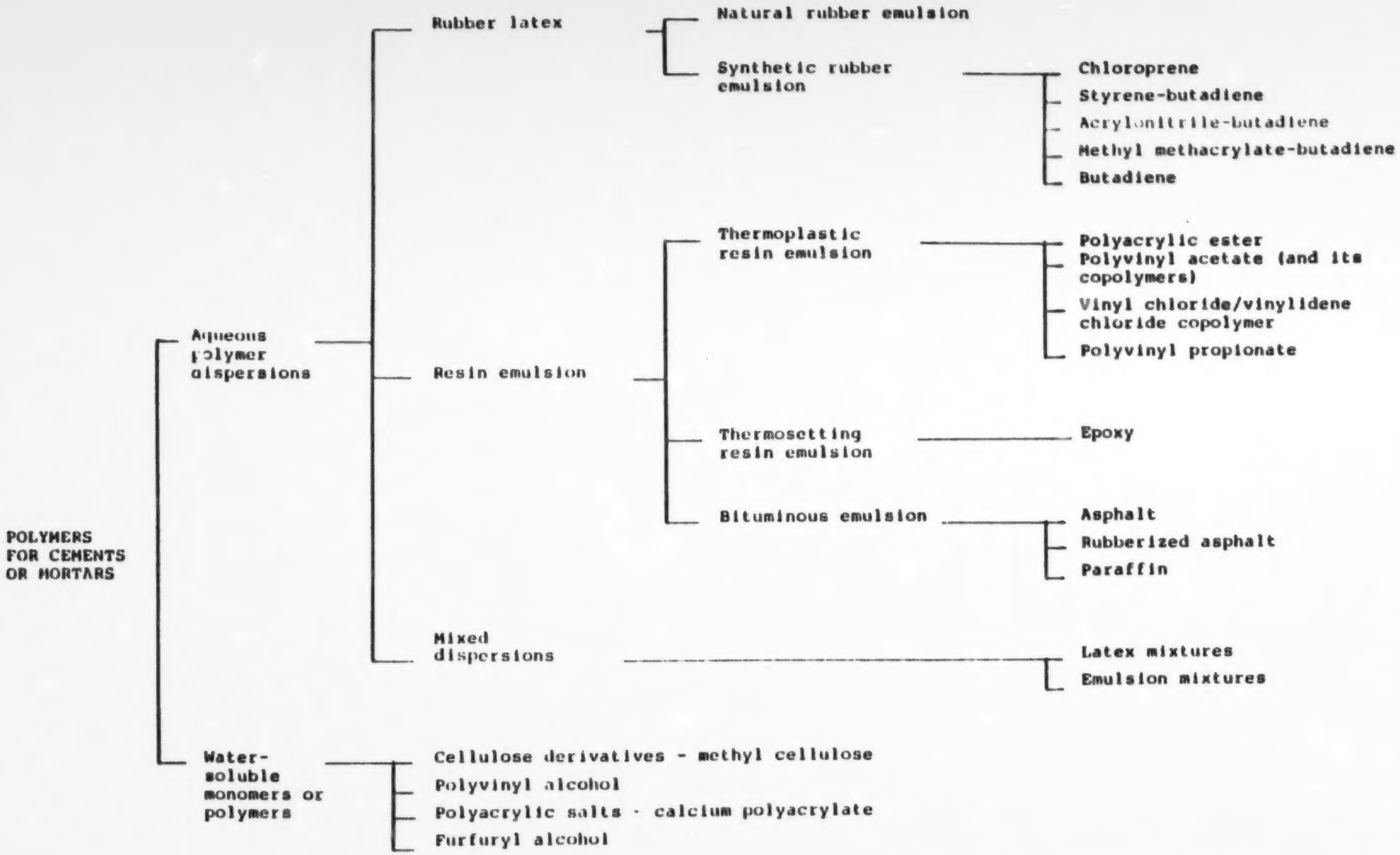
Most polymers are insoluble in water and subject to slow alkaline degradation and usually interfere with the normal hydration process of cement. PPCC process technology therefore seeks to overcome these incompatibilities by a choice of polymer or copolymer that is compatible with the cement.

The two main types of polymer used in these formulations are latexes (or emulsions) and epoxy. Most of the commercial PPCC formulations in the United States and Canada use latex. Utilization of the latter material began about 45 years ago.

Latex-modified concrete represents the oldest user of polymers in concrete. The first British patents describing its use date from 1923 and 1925. Its success is due largely to the fact that it can improve the properties of concrete without requiring a major change in process technology. (30)

7.2 Raw materials

Latexes consist of two types of polymer dispersion or emulsion containing about 50% solids by weight and held in suspension in water by the use of surface-active agents, namely thermoplastic and elastomeric dispersions (or emulsions) - see Figure 55. Polymer latexes are generally vinyl ester, acrylic, styrene, vinyl chloride or butadiene-based copolymers. Many elastomeric latexes are available,


POLYMERS FOR CEMENTS OR MORTARS
Aqueous polymer dispersions
Rubber latex
Natural rubber emulsion
Synthetic rubber emulsion
Chloroprene
Styrene-butadiene
Acrylonitrile-butadiene
Methyl methacrylate-butadiene
Butadiene
Resin emulsion
Thermoplastic resin emulsion
Polyacrylic ester
Polyvinyl acetate (and its copolymers)
Vinyl chloride/vinylidene chloride copolymer
Polyvinyl propionate
Thermosetting resin emulsion
Epoxy
Bituminous emulsion
Asphalt
Rubberized asphalt
Paraffin
Mixed dispersions
Latex mixtures
Emulsion mixtures
Water-soluble monomers or polymers
Cellulose derivatives - methyl cellulose
Polyvinyl alcohol
Polyacrylic salts - calcium polyacrylate
Furfuryl alcohol

Source: Y. Ohama, "Development of Concrete-Polymers Materials in Japan"; Polymers in Concrete, Second International Congress, AUSTIN, Texas, USA , Oct. 25-27, 1978, pp. 121-137.

FIGURE 55: Polymers used for polymer-portland cement concretes and mortars (PPCC)

including styrene-butadiene, acrylonitrile-butadiene and neoprene. Latex PPCC is more flexible but has a slightly lower mechanical strength than polymer PPCC. The typical properties of these latexes are given in Table 15.

Latex PPCC

Latex-modified concrete is manufactured in a similar manner to concrete. The latex is added to a rich portland cement mixture (more than 300 kg/m^3 of cement) in a 0,25 : 0,5 latex-cement ratio by weight. (30) Air entraining agents are not used since latex entrains great quantities of air and anti-foaming agents are usually necessary. The quantity of water required is reduced since about 50% by volume of the latex emulsion consists of water. Latex PPCC is placed in the conventional manner but excessive vibration should be avoided to prevent mater appearing on the surface of the concrete. Latex PPCC setting time is shorter than the setting time for portland cement, viz. generally three days at the most in a humid atmosphere and the rest of the time at ambient temperature.

Epoxy PPCC

Epoxy resins added to the fresh concrete mixture improve its strength. The epoxy system consists of a resin and hardener whose viscosity is usually 125 centipoises or less. This type of resin-modified concrete generally has the advantage of being easier to manipulate since it is less sticky than other types and allows a longer pouring time before setting.

Epoxy resin-modified polymer concrete can be prepared in various types of mixers or by hand. The recommended epoxy:cement ratio is around 1:5 and the resin is added to the mixture once the dry ingredients have been put in. Epoxy resin replaces an equivalent amount of water at the mixing stage. Formulations have been used for thin-layer (2,5 cm) road surface repair at 4 to 38°C. (19)

TABLE 15: Typical properties of polymer latexes for PPCC

POLYMER TYPE	POLYVINYL ACETATE	STYRENE BUTADIENE	ACRYLIC	SARAN[1]	NEOPRENE
Percent solids	50%	48%	46%	50%	42%
Stabilizer type	Nonionic	Nonionic	Nonionic	Nonionic	Anionic
Specific gravity (25°C)	1.09	1.01	1.05	1.23	1.10
Weight per gallon (pounds at 25°C)	9.2	8.4	8.8	10.25	9.3
pH	2.5	10.5	9.5	2.0	9.0
Particle size (Å)	--	2,000	--	1,400	--
Surface tension (dynes/cm^2 at 25°C)	--	32	40	33	40
Shelf life	--	>2 years	Excellent	6 months	--
Freeze-thaw stability	--	5 cycles	5 cycle	None	--
Viscosity (cps at 20°C)	17	24	-250	-15	10

--: Not available

[1] Vinylidene chloride - vinyl chloride copolymer

Note: lb/gal = 119.8 kg/m^3

Å = 10^{-10} metre

dyne/cm^2 = .1 pascal

centipoise = millipascal-second

Source: American Concrete Institute, Committee 548, «Polymers in Concrete»; Detroit, Michigan, USA, 1977, 92 pages, p 18.

7.3 Properties

Although the addition of latex to concrete or mortar means increased strength and ductility, the main advantages are greater durability and good adhesive properties. The properties obtained vary according to the type of latex used and its concentration. In addition, the freeze-thaw durability of this concrete and its abrasion and impact resistance are excellent and its creep is better than that of regular concrete. By way of example, Table 16 shows the chemical resistance of two types of latex-modified mortars. (30)

Research has shown that the increased mechanical performance of resin-modified concrete (latex or epoxy) is obtained when the polymer is added up to an hour after the addition of water to the cement and aggregates. In the case of regulated setting cement, however, the time when the polymer is added has little effect on the final mechanical properties because of the very rapid hydration of this type of cement.

Generally speaking, latex-modified concrete has increased durability due to a reduction in porosity caused by a lower water:cement ratio and the partial filling of the pores by the polymer. When the latexes are mixed with the mortars or the cement, the polymer particles disperse uniformly within the cement paste. During hydration of the paste, the water recedes and the latex forms filamentary membranes in the cement paste. The size of the pores in the cement paste varies from a few Angströms to several thousand Angströms while the latex polymer particles are typically between 500 and 5 000 Angströms. Consequently, only the largest pores can be filled with polymer. The latex, however, reduces the cement's permeability and hence increases its chemical resistance. In general, permeability diminishes with increased polymer content as demonstrated in Figure 56. (38)

The addition of epoxy resin increases the concrete's mechanical strength: compressive strength is in the order of 50-60 MPa, tensile strength is 5 MPa and shear bond strength is approximately 4,4 MPa. (20)

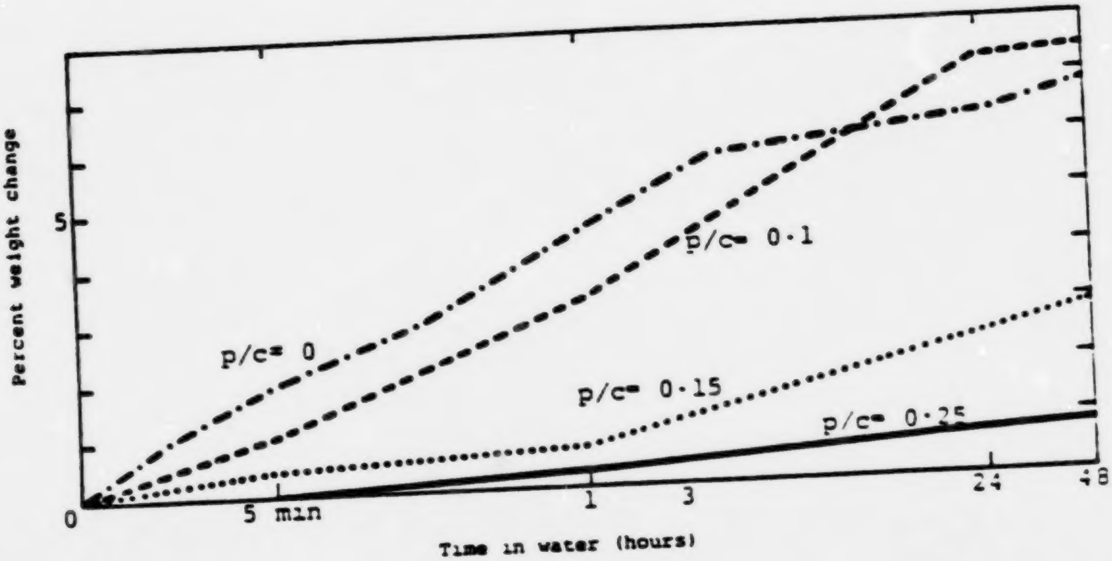
TABLE 16: Chemical resistance of latex-modified mortars

TYPE OF LATEX	CONCENTRATION % WEIGHT (LATEX/CEMENT)	10% HCl	5% ACETIC ACID	PERCENT WEIGHT LOSS AFTER 28 DAYS' IMMERSION				
				5% H_2SO_4	10% NaOH	Xylene	Trichloro-methane	Methyl-isobutyl-ketone
Control		*	66	40	-5	-4	-3	-5
Styrene-butadiene	15%	54	25	46	-3	*	0	*
	20%	17	10	44	-3	2	0	4
Saran **	20%	44	13	29	-2	-5	-3	-5
	25%	37	8	27	-2	-2	0	-2

* Sample completely destroyed

** Vinyl chloride-vinylidine chloride copolymer

Source: Dow Chemical Co., Midland Michigan, U.S.A., 1973



Source: V.P. Rilex, «Polymer Additives for Cement Composites: A Review»; Composite, Jan. 1974, pp 27-33.

FIGURE 56: **Water absorption by mortars with different polymer / cement (polychloroprene latex) ratios**

Tests in Japan have shown that adhesive properties of polymer (polyacrylic ester) and elastomer (styrene-butadiene) modified mortars exposed to the outside atmosphere remain excellent even after ten years (see Figure 57) (39). The tests also showed that incombustibility of these mortars depends much more on the type of polymer than on the polymer:cement ratio applied (see Figure 58). (40)

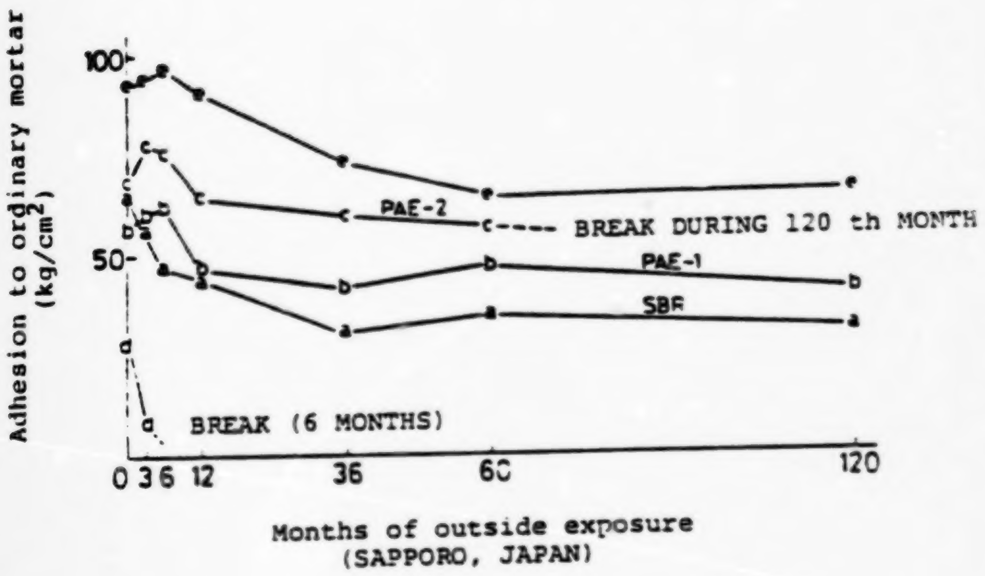
Variations in the formulations of resin-modified concrete makes it difficult to compare the various types, especially when we are not always given all the information on the formulation (such as type of surface-active agent, etc.). Because of the great number of polymer and elastomer types used, the diversity of the dispersing agents and variations in setting conditions, we can safely say that a great deal of work on the determination and correlation of these properties remains to be done if we are to gain a proper understanding of this field. A recent study, for example, attempts to relate porosity and permeability of three types of PPCC to the durability of these materials, based on the fact that deterioration of the concrete is caused by freeze-thaw conditions, chemical attack and steel reinforcement erosion. These conditions are caused by water, carbon dioxide and oxygen penetrating the mortar or concrete. (41)

7.4 Applications

7.4.1 United States

The most frequent applications are for mortars, floors, bridge deck and road surfacing and compounds for the repair of concrete structures and products. (42)

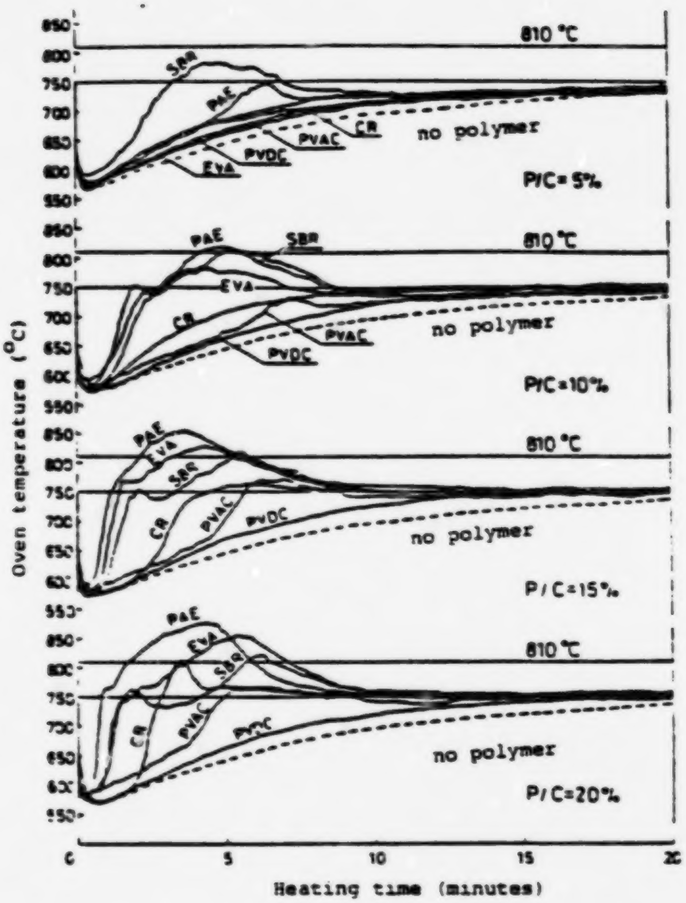
Latex-modified concrete has been used for a number of years to repair deteriorated bridge decks. Its widespread use in the United States is attributable to its ease of application, its good adhesion to the existing concrete and its resistance to freeze-thaw conditions and de-icing salt. Latex PPCC is widely used for placing ceramic tiles owing to its adhesive properties. Epoxy PPCC was



Note: e: unglued mortar sample
c: polyacrylic ester emulsion
b: polyacrylic ester emulsion
a: styrene-butadiene emulsion
d: mortar with no polymer emulsion

Source: K. Okada, Y. Ohama, "Status of Concrete-Polymer Composites in Japan": Polymers in Concrete, Third International Congress, KORIYAMA, Japan, May 13-15, 1981, pp 3-19.

FIGURE 57: **Adhesion of latex mortar to ordinary mortar exposed to the outside atmosphere**



Note: Samples whose temperature does not exceed 810°C conform to JIS Standard A 1321.

CR: Chloroprene emulsion (rubber)
SBR: Styrene-butadiene emulsion (rubber)
PVAC: Polyvinyl acetate emulsion
PVDC: Polyvinylidine chloride emulsion
PAE: Polyacrylic ester emulsion
EVA: Vinyl-ethylene acetate emulsion

Source: Y. Ohama, "Incombustibility of Polymer-Modified Mortars": Polymers in Concrete, Third International Congress, KORIYAMA, Japan, May 13-15, 1981, pp 222-233.

FIGURE 58: Temperature curve of samples placed in an oven maintained at 810°C

developed to provide greater mechanical strength than that offered by latex. It is used for road and bridge repair, industrial floors (43), sanitary floors for the food industry, and as covering for hydraulic works (tailraces, dams, side walls of locks, concrete pillars, etc.). (20)

PPCC road surfaces and bridge decks have been in use in the United States for 20 years now. Tests conducted to date and on-site observation would suggest that the concrete's minimum life expectancy is 15 to 20 years. Thirteen user reports on overlays for 184 bridges are discussed in reference 44.

The use of PPCC mortars to make prefabricated masonry walls for erection on the construction site reduces construction time while simultaneously producing a quality product. Glass fibre-reinforced latex PPCC has been successfully used in the United States to repair the walls of a damaged lock. The 3 mm thick overlay was sprayed on. Laboratory and on-site tests demonstrated the overlay's freeze-thaw durability, its impact resistance and its impermeability. (45)

7.4.2 Japan

The earliest research work on the use of PPCC in Japan was published in 1953 and concerned the utilization of polyvinyl acetate in cement. Initially, the mortars were used primarily for boat decks. Now, PPCC is utilized as construction and paving material, a waterproofing agent, an adhesive and anti-corrosive overlay. The high cost of these materials compared with the performance obtained limits their use, however, and current consumption is around 70 000 tonnes a year. A guide for the use of these products has been available for many years. In 1974, efforts were begun to standardize quality, and tests on the products led to the publication in 1978 and 1979 of five test standards for these products. These factors explain in part why the use of the products is more widespread in Japan than it is elsewhere. The types of latex used and their properties are given in Table 17. Table 18 lists the uses of PPCC in Japan.

TABLE 17: Properties of the main types of PPCC mortar used in Japan

TYPE OF MORTAR	POLYMER-CEMENT RATIO	RESISTANCE (kg/cm^2)		ADHESION IN FLEXURE (kg/cm^2)	WATER ABSORPTION (%)	CONTRACTION OF DRYING (x10^{-4})
		FLEXION	COMPRESSIVE			
Cement mortar	0	30-50	180-200	10-20	10-15	10-15
1	10	40-60	150-170	15-25	10-15	14-16
	20	20-30	40-50	25-30	10-15	18-20
2	10	50-60	180-190	15-25	10-15	13-15
	20	90-100	310-340	25-30	5-7	7-9
3	10	60-100	150-290	25-70	4-10	8-17
	20	70-120	170-320	20-70	2-5	5-17
4	10	60-80	160-180	45-80	4-10	8-11
	20	60-90	140-200	70-80	4-7	6-10
5	10	60-70	160-170	15-25	10-15	9-11
	20	60-70	150-160	25-35	10-15	8-10
6	10	60-90	180-290	15-65	6-13	9-12
	20	60-110	190-320	30-70	3-13	8-16

1: Modified natural rubber emulsion
2: Polychloroprene emulsion
3: Styrene-butadiene emulsion
4: Polyacrylic ester emulsion
5: Polyvinyl acetate emulsion
6: Vinyl-ethylene acetate emulsion

Source: K. Okada, Y. Chama, «Status of Concrete-Polymer Composites in Japan»; Polymers in Concrete, Third International Congress, KORIYAMA, Japan, May 13-15, 1981, pp 3-19.

TABLE 18: Typical applications and composition of resin-modified concrete (PPCC) mixtures in Japan

APPLICATION	SPECIFIC USES	COMPOSITION (BY WEIGHT)			THICKNESS OF COATS (mm)
		CEMENT	SAND	POLYMER DISPERSION	
Floors	Floors in houses, warehouses, factories, offices and bathrooms	1	3	0.2-0.3	5-10
	Corridors, staircases, chemical plants, railway platforms, roads, garages, etc.	1	3	0.3-0.5	10-15
Impermeabilization	Cement roofing, cement and mortar blocks, water tanks, swimming pools, septic tanks, silos	1	2-3	0.3-0.5	5-20
Adhesive	Adhesive for materials glued to concrete walls or floors, including heat insulation	1	0-3	0.2-0.5	-
	Binder for regluing old concrete or mortar	1	0-1	<0.2	-
	Crack repair	1	0-3	<0.2	-
Anti-corrosive surface/coating	Sewage pipes, chemical plant floors, acid-proof tile binder, septic tanks, machine bases, chemical laboratory floors, pharmaceutical warehouses, etc.	1	2-3	0.4-0.6	10-15
Decks etc.	Internal and external boat decks, bridge decks, train floors { Base, intermediate and surface coats	1 1 1	2-3 3 3	0.9-1.0 0.4-0.6 0.5-0.6	1-2 5-6 3-4

Source: Y. Ohama, "Development of Concrete-Polymer Materials in Japan"; Polymers in Concrete, Second International Congress, 1978, Oct. 25-27, pp. 121-137.

8.0 COMPARISON OF THE PROPERTIES OF PPCC, PIC, PC AND GEL-COATED CONCRETE

8.1 Classification

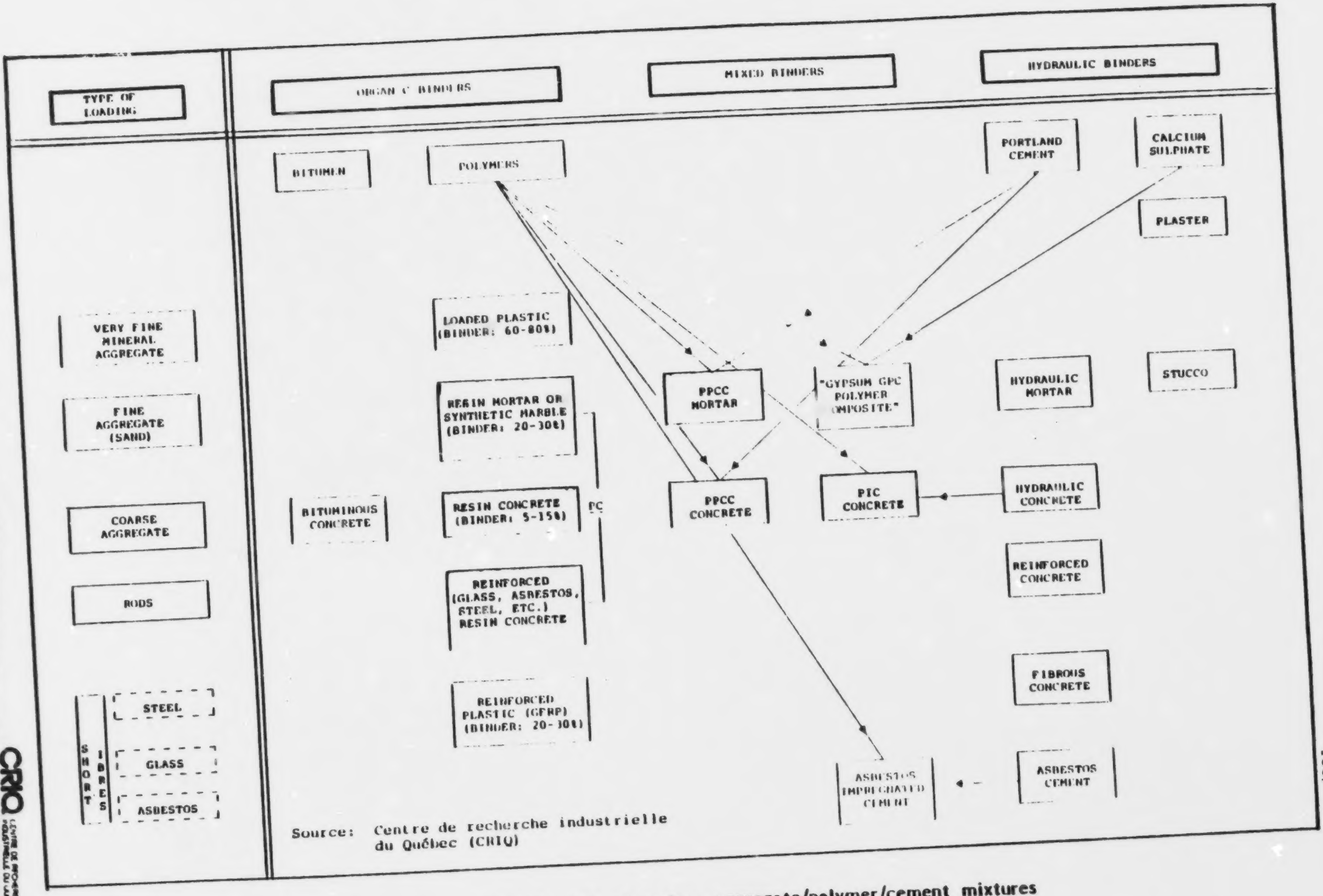
Of the three types of composite discussed here, i.e. PPCC, PIC and PC, only polymer concrete is a polymer composite, the other two being, rather, concrete composites as shown in Figure 59. These three types of composite represent only a fraction of all the possible combinations of binder and aggregate, some of which are well known while others are still at the experimental stage.

Polymer concrete is in fact a highly loaded plastic where the aggregate-filler loading is at its maximum and that is why portland cement concrete methods have to be used to produce it. If the proportion of polymer is increased, techniques applicable to more plastic materials such as those employed in the ceramic industry should be used. If we continue to increase the polymer content, we get loaded resin such as glass fibre-reinforced plastic (FRP).

Concrete is a porous composite made up of aggregates and cement consisting of silicate crystals. The porosity is due mainly to the excess water used for the hydration of the cement. Figure 60 illustrates porosity in the cement phase of concrete.

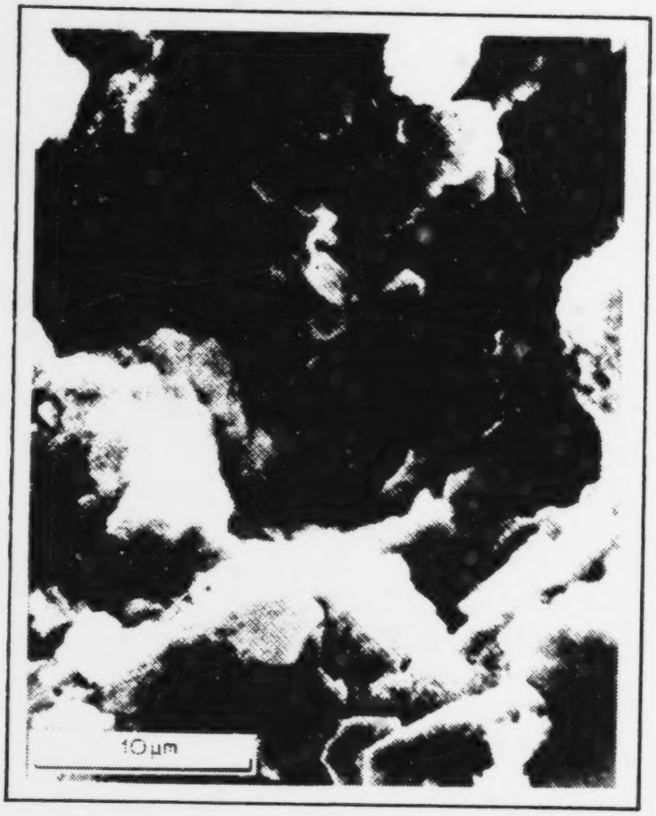
Through the impregnation technique, the concrete's tiny canals and pores are partially filled (on the surface or deeper down, as the case may be) as shown schematically in Figure 61. Polymer-impregnated concrete (PIC) is thus a porous composite partially filled with another matrix so as to achieve, in most cases, an impermeable surface.

Polymer-portland cement concrete (PPCC) is a composite with reduced porosity throughout its mass, the voids between the silicate crystals being partially filled with a filamentary polymer network as shown in Figure 62.


TYPE OF LOADING
ORGANIC BINDERS
MIXED BINDERS
HYDRAULIC BINDERS
BITUMEN
POLYMERS
PORTLAND CEMENT
CALCIUM SULPHATE
PLASTER
VERY FINE MINERAL AGGREGATE
LOADED PLASTIC (BINDER: 60-80%)
FINE AGGREGATE (SAND)
RESIN MORTAR OR SYNTHETIC MARBLE (BINDER: 20-30%)
PPCC MORTAR
"GYPSUM GPC POLYMER COMPOSITE"
HYDRAULIC MORTAR
STUCCO
COARSE AGGREGATE
BITUMINOUS CONCRETE
RESIN CONCRETE (BINDER: 5-15%)
PC
PPCC CONCRETE
PIC CONCRETE
HYDRAULIC CONCRETE
RODS
REINFORCED (GLASS, ASBESTOS, STEEL, ETC.) RESIN CONCRETE
REINFORCED CONCRETE
SHORT FIBRES
STEEL
GLASS
ASBESTOS
REINFORCED PLASTIC (GFRP) (BINDER: 20-30%)
FIBROUS CONCRETE
ASBESTOS IMPREGNATED CEMENT
ASBESTOS CEMENT

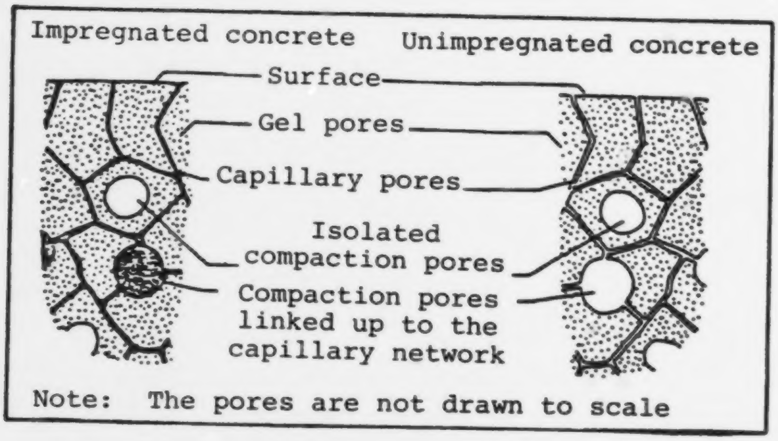
Source: Centre de recherche industrielle du Québec (CRIQ)

FIGURE 59: Classification of various aggregate/polymer/cement mixtures according to type of binder



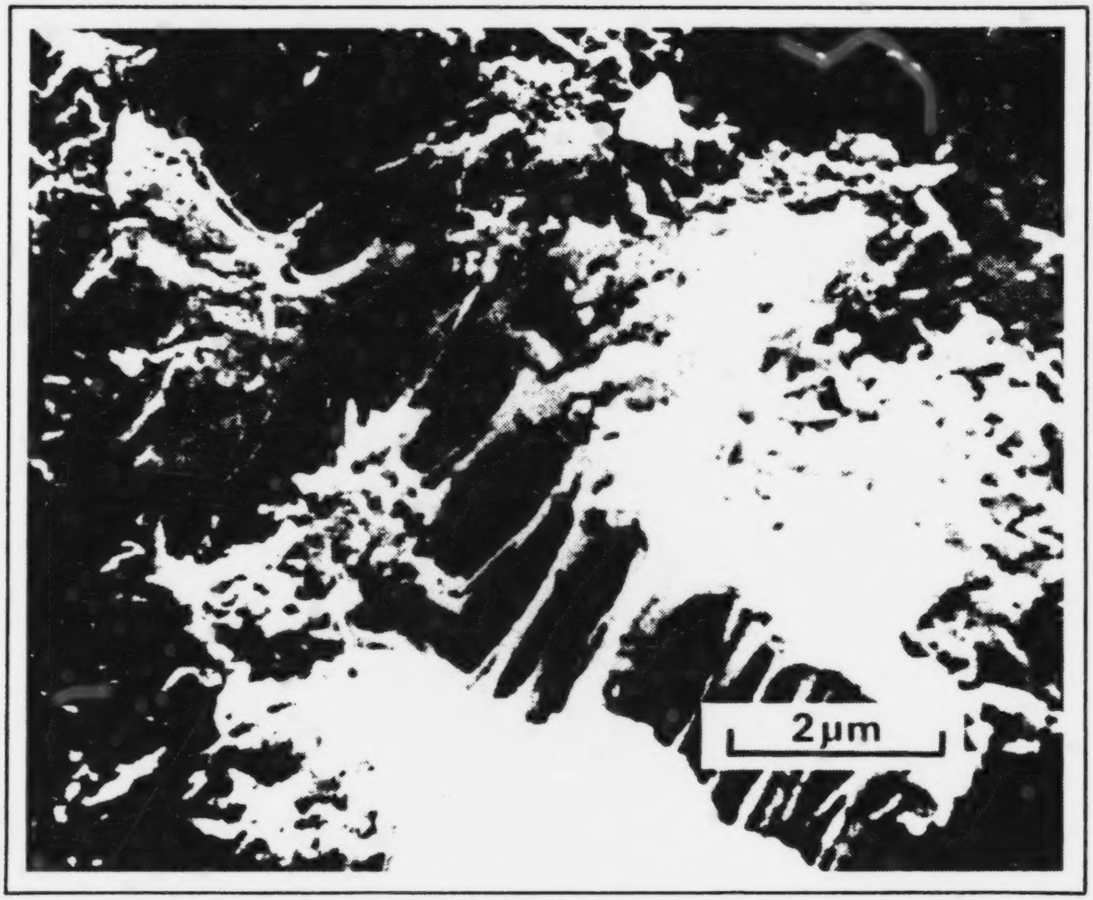
Source: R. Naravan Swamy, Univ. of Sheffield, UK, "Review: Polymer Reinforcement of Cement Systems, Part I: Polymer Impregnated Concrete"; J. of Materials Science, Vol. 14, 1979, pp 1521-1553.

FIGURE 60: Microstructure of hardened cement paste showing silicate crystals and the pores between them


Impregnated concrete
Unimpregnated concrete
Surface
Gel pores
Capillary pores
Isolated compaction pores
Compaction pores linked up to the capillary network
Note: The pores are not drawn to scale

Source: R. Narayan Swamy, Univ. of Sheffield, UK, "Review: Polymer Reinforcement of Cement Systems, Part I; Polymer Impregnated Concrete"; J. of Materials Science, Vol. 14, 1979, pp 1521-1553.

FIGURE 61: Difference in structure between impregnated and unimpregnated concrete



Source: R. Narayan Swamy, Univ. of Sheffield, UK, "Review: Polymer Reinforcement of Cement Systems, Part I: Polymer Impregnated Concrete"; J. of Materials Science, Vol. 14, 1979, pp 1521-1553.

FIGURE 62: Microcrack in a PPCC mortar (SM-100: styrene-butadiene copolymer) partially filled with polymer fibres

Gel-coated concrete can be classed as an portland type concrete impregnated on the surface only. The important feature here is the adhesion between the thin film of epoxy resin and the porous concrete.

8.2 Gel-coated concrete

The company Francon studied the casting of concrete products provided with a gel coat according to the inverted mould technique. The steps of this production technique are as follows:

- the gel coat, usually an epoxy, is applied to the mould after application of the mould-releasing agents;
- once the gel coat has hardened, a second adhesive epoxy resin layer is applied;
- the concrete is then poured over the two layers of resin.

This method offers the following advantages:

- the aesthetic appearance is improved in terms of the surface finish and the colouring of the gel coat;
- the gel coat increases the concrete's life insofar as its integrity is not impaired (e.g. by abrasion, ultra-violet rays, temperature cycles, etc.);
- the quantity of resin is minimal compared with that for PIC and PPCC.

Its drawbacks are as follows:

- Resistance to freeze-thaw conditions and corrosion depends on a thin film. Products that are subject to impact or abrasion run a serious risk of having their coating damaged.

- The market for products prefabricated according to this technique is limited mainly to aesthetic applications and corrosion-resistant applications in gentle environments.

- The production cycle for these products is slower and more complex than for equivalent prefabricated concrete products and much slower than it is for resin concrete products.

- The production cost is higher than it is for equivalent portland cement concrete products without a gel coat because of additional expenses incurred through the purchase of raw materials (resin and adhesive at approximately 1,00 $ per square foot), depreciation of moulds (approximately 1,00 $/sq. ft) and extra labour (2.00 $/sq. ft). (46)

- The weight of prefabricated products cannot be reduced as it can with resin concrete since the mechanical strength of the cement concrete is not increased.

One cannot really speak of typical applications for this product since its present uses are part of an experiment to determine its behaviour "in the field".

8.3 Polymer-portland cement concrete (PPCC)

As shown in Figure 55, there are many types of polymer-portland cement concrete and their properties differ according to whether the resin added is epoxy or latex. The latex group comprises many different products. The advantages of PPCC products in relation to regular cement concrete products are:

- good adhesion to existing concrete;
- double tensile strength;
- reduction in pores and increase in freeze-thaw stability;
- chemical resistance increased by a factor of 1 to 6;
- increased abrasion resistance;
- rapid setting time in the case of epoxy resins;
- easy incorporation of polymer into the cement mixture.

The following are some disadvantages:

- The concrete obtained remains porous even if porosity is reduced. In certain cases this porosity can be advantageous but it limits the concrete's strength.
- The mechanical and chemical properties are inferior to those of PC and PIC.
- The selling price varies considerably according to formulation but it is in the same range as that for PC and PIC.

The typical applications of these products are as follows:

- the repair of concrete constructional works that have deteriorated or show flaws in design or manufacture (buildings, roads, parking lots and hydraulic works) and the protection of industrial floors;
- their good adhesive properties have for years been utilized in mortars for laying bricks (prefabricated panels), stones and ceramic tiles.

8.4 Polymer-impregnated concrete (PIC)

Impregnation of portland cement concrete improves its mechanical properties and strength significantly:

- abrasion resistance is increased 2 to 5 times;
- creep resistance is increased;
- tensile and compressive strength is increased 4 times;
- almost complete permeability is achieved (1-2% water absorption as compared with 5-6% or more for concrete);
- chemical resistance is improved by a factor varying from 2 to 5;
- impregnation of large structures can be carried out superficially thus reducing the amount of polymer used;
- the material is structurally strong and durable in harsh environments.

Even if polymer impregnation improves the concrete's properties significantly, however, the production cost of prefabricated PIC products seems too high for the majority of potential applications. The impregnation technique currently employed requires the concrete to be dried and would make on-site production more difficult and costly. Moreover, methyl methacrylate (MMA), the monomer most often used, is relatively expensive.

Typical applications are of two types:

- Repair and protection of concrete works and structures:
  - deteriorated buildings;
  - tailraces and artificial lakes on dam sites;
  - protection of reinforced concrete works against de-icing salt: roads, bridges, viaducts;
  - coating for industrial floors.
- Prefabricated PIC elements:
  - vertical supports for mines (USSR);
  - pipes.

8.5 Resin concrete (PC)

There are many different types of resin concrete (PC), depending on the type of resin used (epoxy, polyester, acrylic, furan, polyurethane, etc.). Although properties can be optimalized for a specific application by choosing the appropriate resin or aggregates, there are a number of advantages all types of resin concrete share:

- adjustable setting time (from under a minute to several hours), so that very rapid mass production can be achieved;

- easy casting using a variety of shapes with or without inserts;
- better aesthetic appearance in terms of surface finish and colours;
- mechanical strength 4 to 5 times better than that of portland cement concrete;
- very good chemical resistance;
- higher abrasion resistance;
- impermeable and hence exceptional freeze-thaw stability;
- good adhesion to concrete and existing resin concrete;
- good dielectric properties;
- reduced weight and size in relation to equivalent cement concrete products;
- very good vibration absorption coefficient.

The main drawbacks of resin concrete are:

- considerable creep at high temperatures (100°C and above) owing to the nature of the binders;
- high cost of resins compared with the cost of cement.

Typical applications utilize one or other of the characteristics of the material replacing materials such as stone, ceramics, steel, reinforced plastic (FRP) and concrete unless use of the latter is recommended. We are concerned here mainly with prefabricated products (such as facing panels, conduits, electric insulators, tanks, etc.) and application for the protection or repair of concrete works and structures (bridges, hydraulic works, acid-resistant floors, easy-to-maintain surfaces for the food industry, etc.). Table 19 gives a comparison of the mechanical properties of materials that provide competition for resin concrete.

TABLE 19: Comparison of the average mechanical properties of resin concrete and other materials

	DENSITY (lb/cu ft)	STRENGTH		MODULUS OF ELASTICITY (10^6 psi)	STRENGTH/DENSITY RATIO (psi-cu ft/lb)		ELASTI-CITY -(10^4)
		TENSILE (psi)	COMPRESSIVE (psi)		TENSILE	COMPRESSION	
Resin concrete(1)	140	1,400	20,000	5.3	10	143	3.8
Portland cement concrete(1)	156	250	5,000	3.6	1.6	32	2.3
Polymer(1)	62	7,000	15,000	0.4	113	242	0.6
Aluminium(1)	165	30,000	25,000	10	182	152	6.1
Steel(1)	470	70,000	42,000	30	143	86	6.1
Glass(1)	137	7,000	300,000	10	51	2,190	7.4
Reinforced Plastic(2)	86-100	9-18,000	15-25,000	8-1, 8	143	212	
Granite(3)	160-190	---	13-55,000	4-16	---	195	5.7
Marble(3)	165-179	300-1 700(5)	8-27,000	5-12	6	102	4.9
Ceramics(4)	150	5,000	40-60,000	10	33	333	6.6

Sources: (1): E. Kirhikovali, Adhesive Eng. Co., CA, USA; "Polymer/Concrete Composites - A Review"; Polymer Engineering Science, Vol. 21, No. 8, 1981, pp 507-509.

(2): Fiberglass Canada Ltd, "An Introduction to Fiberglass-Reinforced Plastic Composites", TORONTO, 44 pages.

(3): L.S. Marks, McGraw Hill, "Standard Handbook for Mechanical Engineers", NEW YORK, 7th ed., pp 6-190.

(4): J.E. Schroeder, "An Evaluation of Polysil as an Insulating Material", IEEE Transactions of Electrical Insulations, Vol. EI-16, No. 5, Oct. 1981, pp 446-52

(5): Engineering Materials Handbook, McGraw-Hill.

ENERGY CONTENT

Because resin concrete binders have a petrochemical origin, it might be supposed that the polymer concrete's energy content, i.e. the energy necessary to manufacture the product, is high. If we compare resin concrete with products such as wood, sheetrock, glass wool, asbestos cement and reinforced concrete, however, we find that the values are similar, whereas materials like steel, aluminium, glass and plastics have an energy content 5 to 50 times higher than that of resin concrete (see Table 20).

TABLE 20: **Energy content of construction materials**

MATERIALS	ENERGY CONTENT (MJ/kg)	(MJ/litre)
Sand, gravel	0.1	0.16
Clay bricks	6.0	11.0
Portland cement	6.4	8.0
Sheetrock	3.6	2.9
Glass	21	56
Glass wool	14	2.2
Asbestos cement	5.1	9.0
Premixed cement	0.8	1.9
Prefabricated steel-reinforced concrete elements	2.0	4.7
Reinforced concrete	2.5	6.0
Steel	30	236
Steel reinforcing	23	180
Aluminium	120	325
Lumber (sawn)	4	2.4
Tar	20	20
Plastic (average value)	40	40
Resin concrete*	4.9	5.4

* Resin concrete: 90% aggregates, 10% resin

Source: P.C. Kreijger, "Energy Analysis of Materials and Structures in the Building Industry"; Applied Energy, Vol. 5, No. 2, Apr. 1979, pp 141-157.

COSTS

By way of comparison, the cost of raw materials for synthetic marble is between 25 $ and 30 $ (approx.) per cubic foot, for polyester resin concrete between 12 $ and 15 $ (approx.) per cubic foot and for portland cement concrete 2 $/cu. ft. These prices may vary rather significantly according to the type of resin used, especially if one is trying to obtain optimal properties for an industrial application.

When comparing resin concrete products with equivalent concrete products, we have to do more than consider the kilogram or cubic metre cost of the raw materials. A fair comparison can be made only by examining the total cost (raw materials, production, transportation, installation, maintenance, etc.) in relation to the life of the product or structure. Cost-benefit studies of this kind are not available at present, however. Table 21 gives some of the advantages of resin concrete for products used in construction.

Moreover, although the cost of raw materials for resin concrete is 5 to 10 times higher than for cement concrete, the use of automated mass production equipment reduces the cost of the finished product considerably.

Experience with continuous mixing equipement has shown that the production cost of resin concrete products is around 1.5 to 2 times the cost of comparable concrete products. Compared with batch production machinery, continuous mixers are a boon because they reduce the cost of resin to a minimum, cut down on labour costs and require less investment in moulds, factory space, etc.

TABLE 21: Advantages of resin concrete over hydraulic concrete with regard to prefabricated products used in construction

FACTOR	RESULT IN FAVOUR OF SYNTHETIC RESIN CONCRETE	REASON
Reduction in material	50 to 65% by volume	Reduced thickness of walls as a result of much greater strength; smaller dimensions (internal diameters obtained on the basis of a better surface quality)
Gain in weight	50 to 65%	Obtained through a reduction in material (density attributable to a large quota of filler, roughly comparable to cement concrete)
Fewer moulds and less storage space for finished products	30 to 40% depending on mechanization of production	Mould release after only 4 to 5 minutes; finished products can be transported after 1 to 2 hours
Reduction in handling costs	20 to 30%	On account of reduced weight and size
Reduction in cost of transport to construction site	20 to 30%	As a result of reduced unit weight, smaller loading space, simplification of loading procedures
Reduction in construction time and construction cost	Up to 80%	In many cases, as a result of elimination or simplification of foundations, elimination of insulating coats of paint; great dimensional precision; easier handling (in most cases without additional equipment)

Source: Respecta Inc., Düsseldorf, Federal Republic of Germany

By comparing the cost of various facing materials, we can obtain an idea of the position of resin concrete in relation to other materials on the market. Such a comparison would be very speculative, however, since the cost of panels varies greatly according to the quality of the finish (regular, exposed aggregate, architectural, etc.), the size of the panels, the number of identical sections, the blocking required, etc. Similarly, a panel's weight and number of anchorage points will affect the installation cost. The cost of the panel will also have a greater or lesser bearing on the cost of the supporting structure depending on whether this will be steel or reinforced concrete. Table 22 gives the average price of some facing materials.

Resin concrete ranks as an "aristocratic" architectural material and it is currently competing with materials in this category (stone, FRP, architectural concrete, etc.). Because of its great potential in terms of casting and surface finish, resin concrete has in the past been earmarked for production in small batches, resulting in prohibitive unit costs arising from the cost of the moulds and the insufficiently automated production process. To compete effectively with concrete, resin concrete must be mass produced in a fully automated manner so that it can redeem the cost of the moulds and use its main asset at the manufacturing stage: very rapid production cycles.

TABLE 22: Comparison of certain materials used for prefabricated facing panels

	Resin concrete (polyester)	Hydraulic concrete	Fibrous concrete (GRC)	Brick	Granite
Approximate cost ($/sq ft)	10-20	5-12	7-15	8-10	10-20
Weight (kg/m^2) (thickness)	34-48 (2 cm)	130 (5 cm)	22-70 (1-3cm)	125 (10 cm)	80 (3 cm)

PART II

STATE OF THE ART IN CANADA

The second part of the study offers an overview of instances in which resin concrete products have been put to use in Canada.

In addition, it has been possible, on the basis of the opinions of manufacturers and users, to identify certain constraints impeding the development of resin concrete products in Canada and to suggest action in the fields of R&D and information services that might contribute to the growth of the Canadian polymer concrete industry.

Finally, the study presents an overview of the Canadian market for some PC, PIC and PPCC products.

9.0 CANADIAN PRODUCTS AND USES: PC, PIC AND PPCC

9.1 Resin concrete (PC)

During the last decade, Quebec in particular has developed an interest in resin concrete. Plastibéton Inc. has been producing the material commercially since 1972 for construction projets in Quebec, Ontario, the Canadian West and abroad. In the past few years, other Quebec companies such as Francon and Janin Construction have also started producing resin concrete.

The examples that follow will give the reader an idea of the possibilities of polymer concrete and its fields of application. These examples should not, however, be regarded as an exhaustive list of the uses of resin concrete in Canada. Numerous repair projects using small quantities of epoxy resin concrete have been carried out on parking lots, roads, hydraulic works and other structures.

9.1.1 Facing panels for public buildings

According to the information obtained, it would seem that Plastibéton Inc. was the first company in Canada to manufacture resin concrete facing panels. The first commercial products date from 1972 (see Table 23): exposed aggregate panels, coloured or aggregate ribbed panels. The company still produces this type of panel on request according to the aesthetic requirements of the customer (see Figure 63).

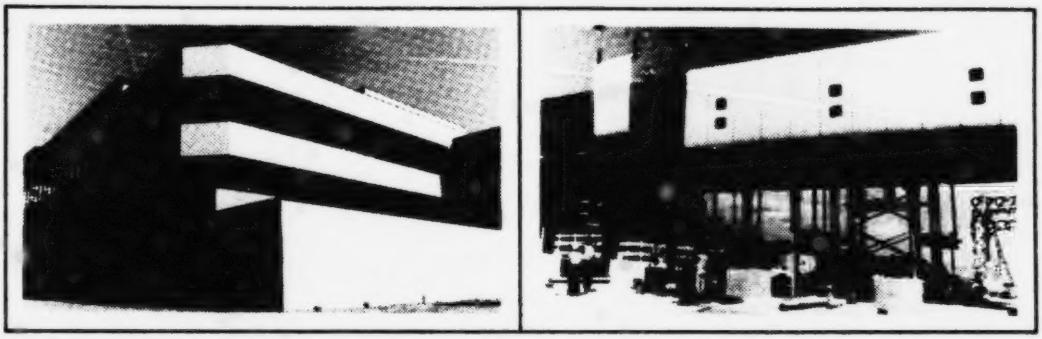
In 1980, Janin Construction produced sandwich-type resin concrete insulating panels for Bois-Joli School in Sept-Iles, Quebec. The thermal insulation is completely embedded in the resin concrete mass. The panels are both light and non-conducting (see Figure 64).

TABLE 23: Examples of projets implemented by Plastibéton Inc. (Canada)

PROJECT	DESCRIPTION	DATE OF PROJECT
Maison Robert Notre-Dame street Montreal, Quebec	Beige exposed aggregate panels	August 1972
Torbay Development St-John's, Newfoundland	Balconies consisting of white exposed aggregate panels	November 1972
Dr. P. Ricard's residence 79 Laforêt, Répentigny	Brown ribbed sandwich-type panels	April 1973
Caisse Populaire Laval-Centre 1599, Boul. St-Martin Chomedey, Laval, Quebec	White sculptured sandwich-type panels	November 1973
Alcan Cie Chicoutimi, Quebec	Chemical-resistant engine mounting	December 1973
Edifice Industriel Place Trans Canada Longueuil, Quebec	Brown exposed aggregate panels	January and July 1974
Brasserie La Broue Inc. Lauzon, Quebec	Brown ribbed sandwich-type panels	February 1974
Centre Médical de Lachine 3344, Notre-Dame Lachine, Quebec	Ribbed brown-aggregate panels	November 1974
Centre d'Achats Jean-Talon 6868, Jean-Talon Montreal, Quebec	White aggregate panels	March 1975
Hôpital de Lanaudière Joliette, Quebec	White aggregate panels	May 1976
Metropolitan Transit Bureau Metro Stations Montreal, Quebec	Blue and orange indoor and outdoor furniture	November 1976
Metropolitan Transit Bureau Metro Stations Montreal, Quebec	Concrete metro rails	April 1977

TABLE 23: Examples of projets implemented by Plastibéton Inc. (Canada) (Cont'd)

PROJECT	DESCRIPTION	DATE OF PROJECT
Apartments on Nuns Island Montreal, Quebec	Benches and tables (exposed aggregate finish)	June 1977
Metropolitan Boulevard Montreal, Quebec	61,000 square ft of 7' x 17' x 1" curved panels for covering the lateral surfaces of the raised freeway	October 1977
Centre de données fiscales Shawinigan-South, Quebec	Semicircular panels for covering 250 interior steel columns	January 1978
Highway 220 Dorval, Quebec	500 lin. ft New-Jersey type median strip in lengths of 20'	July 1978
Metropolitan Boulevard Montreal, Quebec	100,000 sq. ft of 7' x 17' x 1" curved panels for extending the lateral surfaces of the raised freeway	October 1978
Metro Stations Montreal, Quebec	Red 1' x 6½' x 9" panels with openings for emergency niches	October 1978
Villa-Maria Metro Station Montreal, Quebec	Furniture in 5 different colours, smooth finish: benches, 8' and 6' diameter ornamental plates, 5' x 7' x 7' outlet grills, metro map panels, etc.	April 1979
Metropolitan Boulevard Montreal, Quebec	1½ miles of New-Jersey type median strip in 20' - long sections	November 1979
International Airport	Counters, benches, gutters - various finishes and colours	June 1979

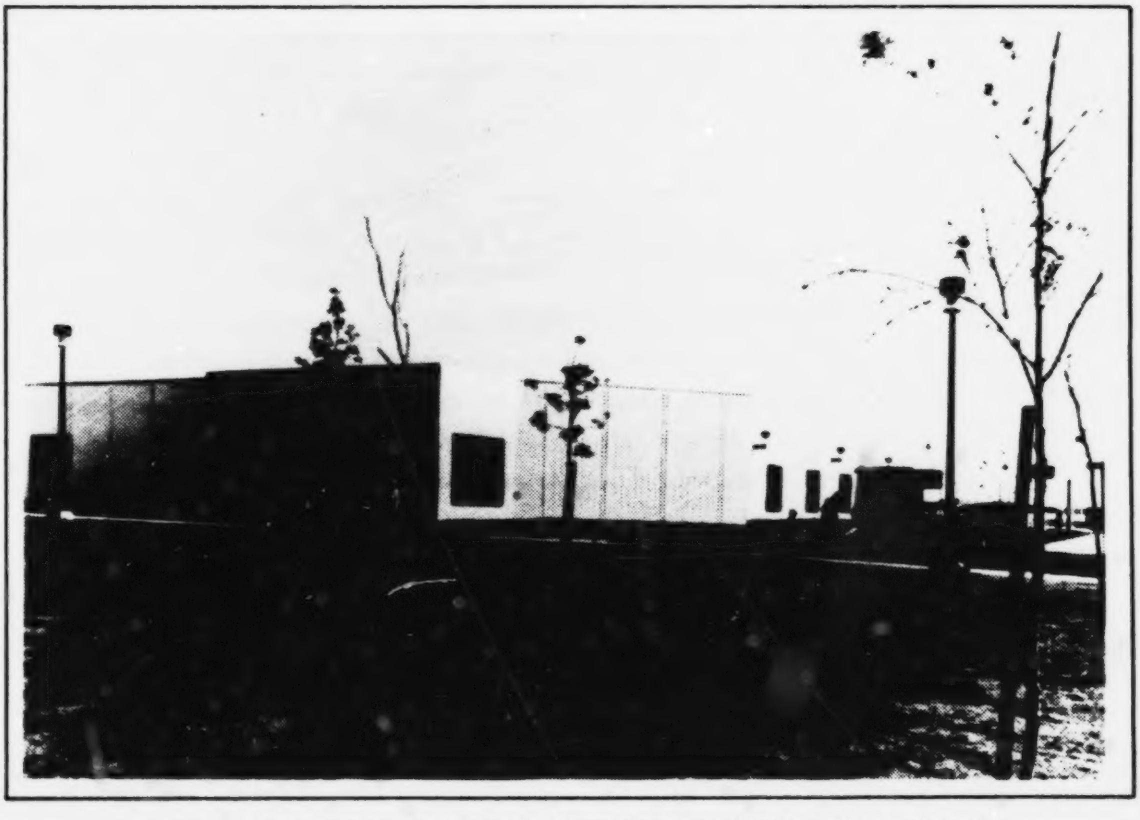


Hôpital de Lanaudière, Joliette

Toll plaza, George Washington Bridge, New York (1981)

Source: Plastibéton Inc. documentation (Montreal, Quebec)

FIGURE 63: Flat and curved architectural panels produced by Plastibéton Inc.



Source: Janin Construction Ltée documentation (Quebec City, Quebec)

FIGURE 64: Use of sandwich-type resin concrete panels with built-in insulation
(Bois-Joli School, Sept-Iles, Quebec)

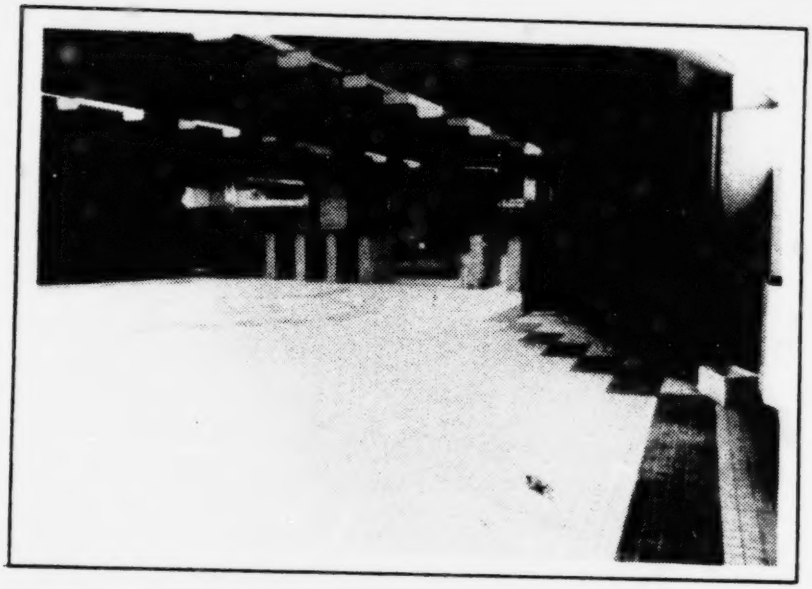
9.1.2 Montreal Metro

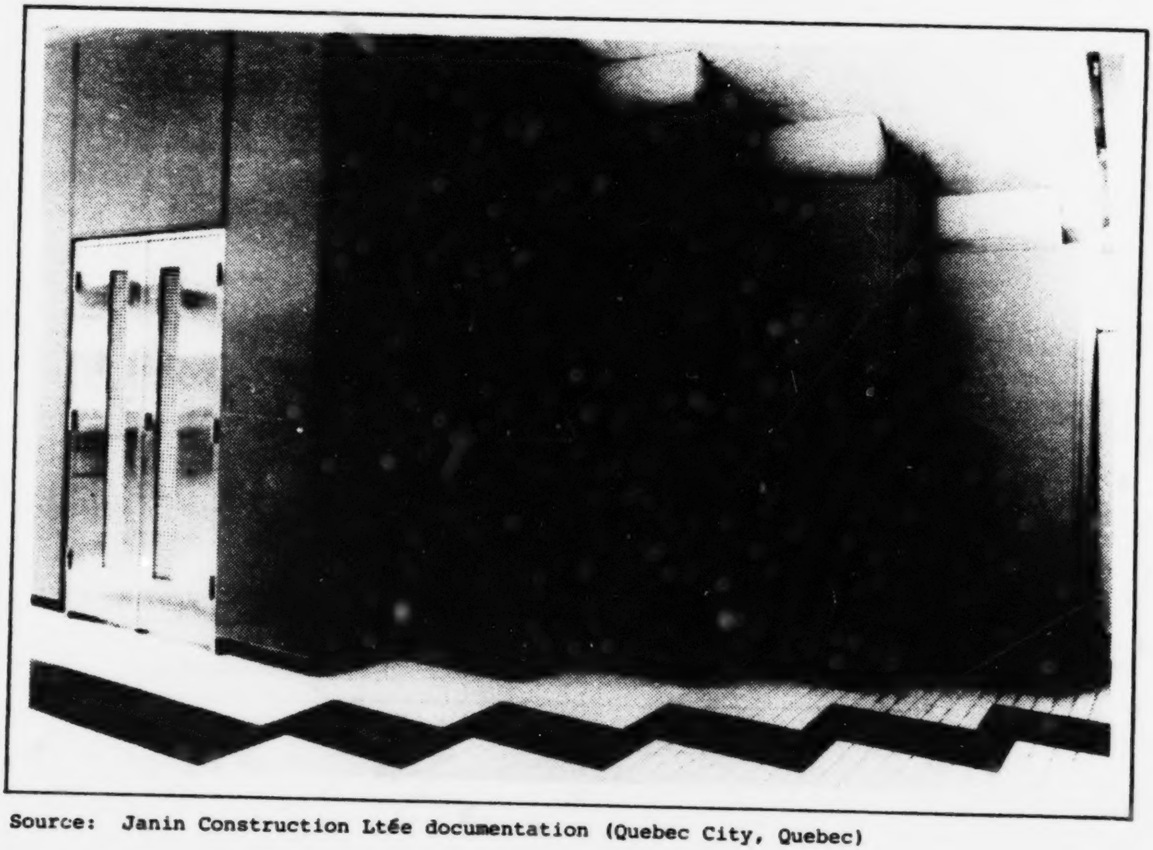
The finishing materials used for the Montreal metro stations were specially designed for external use, fire resistance, non-emission of toxic gases and easy maintenance. In addition, the stations have almost all been decorated differently for aesthetic reasons and for easy identification by users.

Plastibéton proposed to the Metropolitan Transit Bureau of the Montreal Urban Community (CUM) that resin concrete be used for finishing work in the metro stations. The material proved attractive on account of its:

- Resistance to fire (provided the proportion of resin is low and flame-retardants are added).
- Aesthetic potential. Ordinary concrete has a dull colour and few vivid colours are available for brick, tile or stone.
- Easy maintenance - e.g. felt-pen graffiti can be readily removed with alcohol.

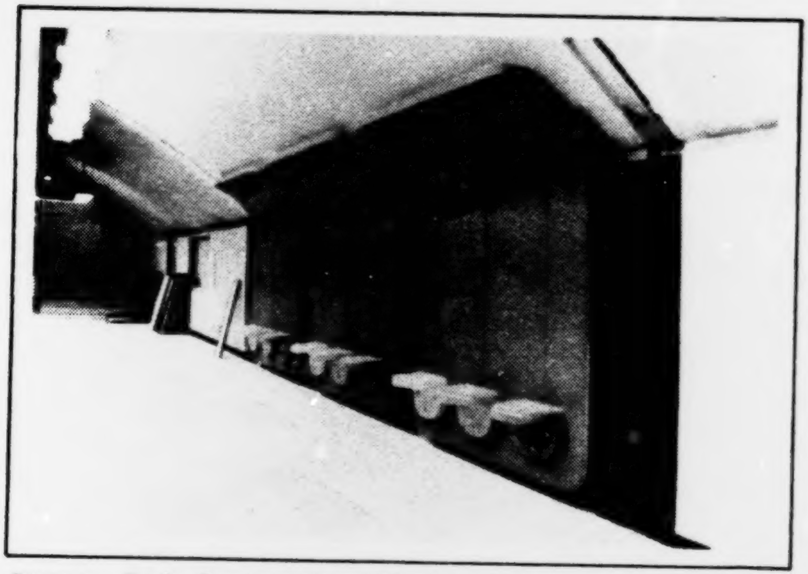
Three stations are currently using polyester concrete panels and another, which is in the process of construction, is also slated to have them. The panels were manufactured by Plastibéton Inc. and Janin Construction. In addition to the panels, resin concrete ornamental pieces and benches have been produced. Figures 65 to 69 give some examples of the application of resin concrete in Montreal metro stations.





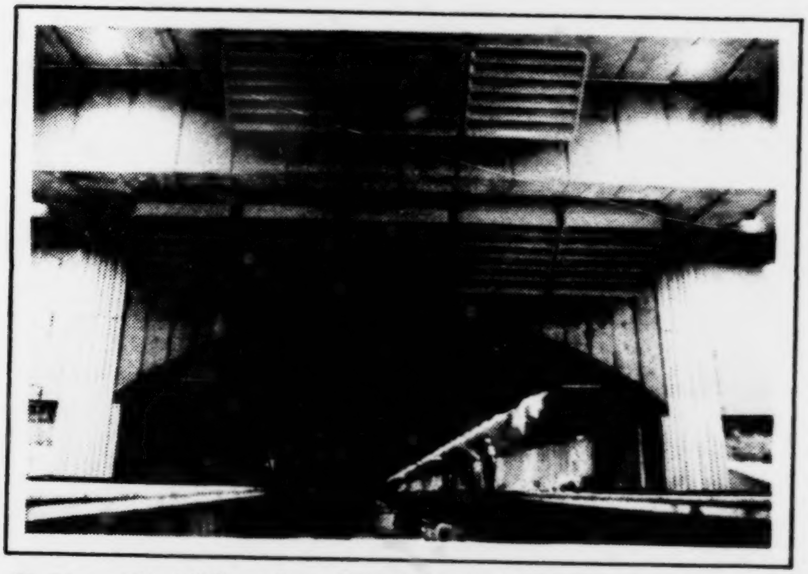
Source: Janin Construction Ltée documentation (Quebec City, Quebec)

FIGURE 65: Wall panels (Plamondon Station, Montreal Metro)



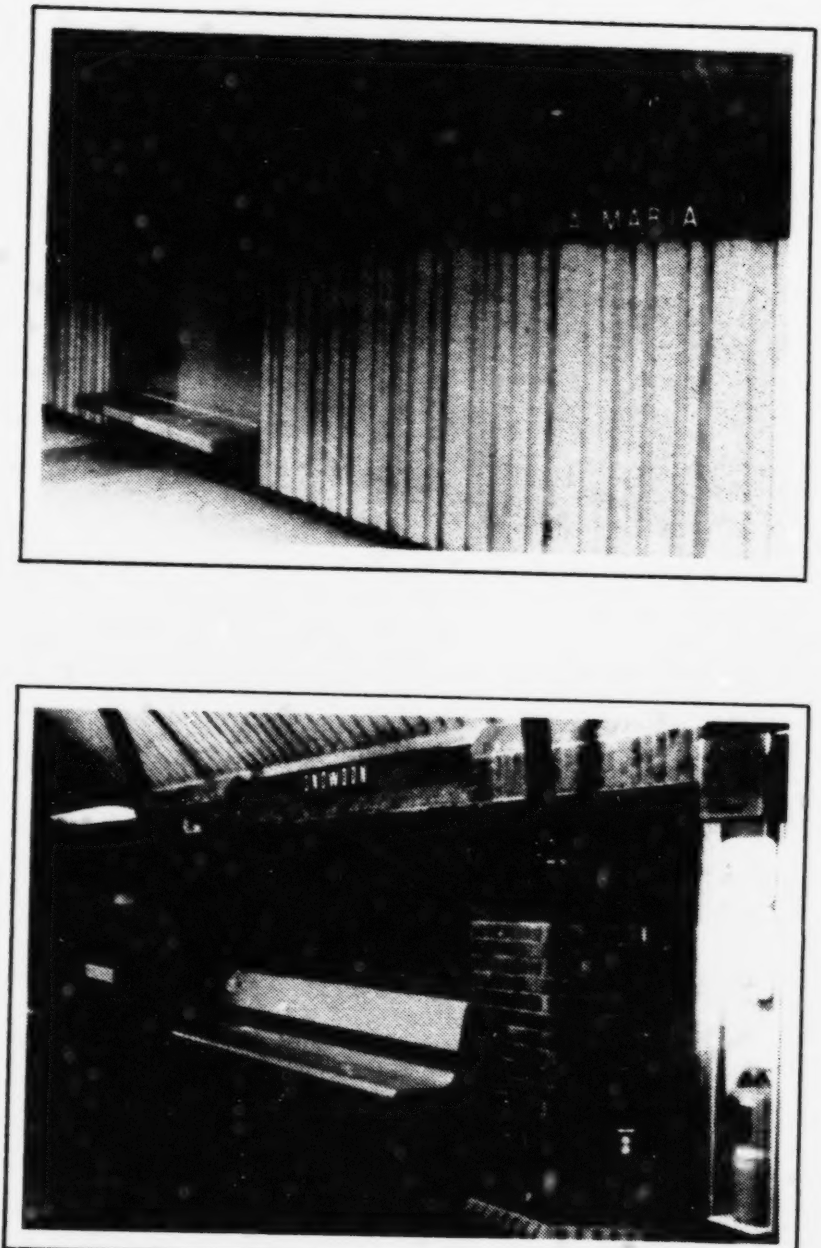
Source: Janin Construction Ltée documentation (Quebec City, Quebec)

FIGURE 66: Polyester concrete seats and curved panels (Plamondon Station, Montreal Metro)



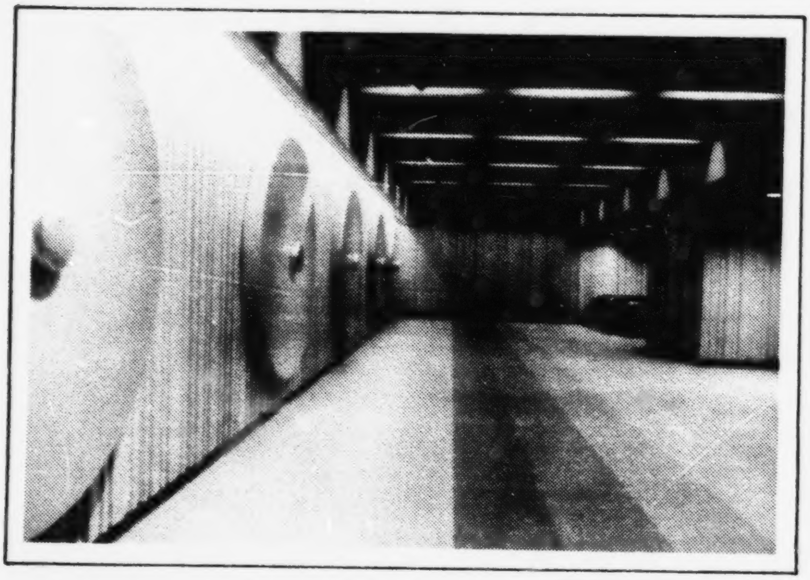
Source: Plastibéton Inc. documentation (Montreal, Quebec)

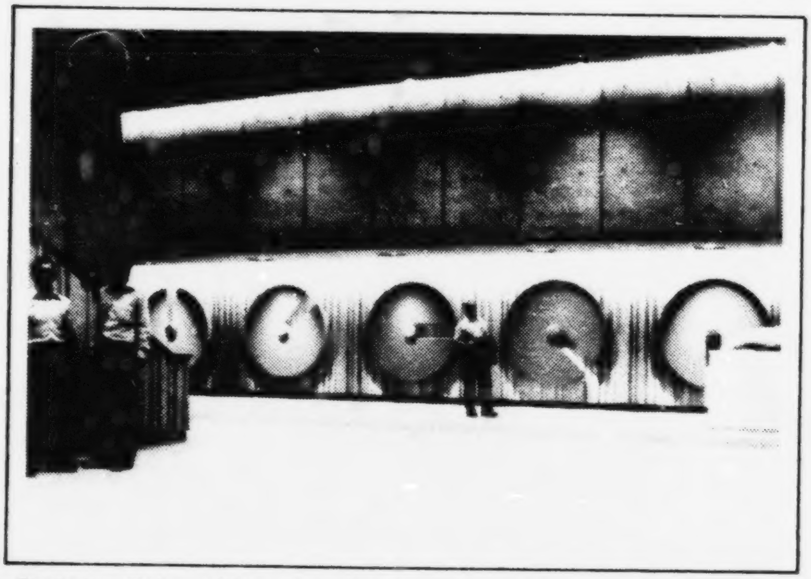
FIGURE 67: Outlet grills
(Villa-Maria Station, Montreal Metro)



Source: Metropolitan Transit Bureau, Montreal Urban Community

FIGURE 68: Polymer concrete seats (Montreal Metro)





Source: Metropolitan Transit Bureau,
Montreal Urban Community

FIGURE 69: Ornamental polymer concrete structures (Villa-Maria Station, Montreal Metro)

9.1.3 Street furniture

The City of Montreal and the Montreal Urban Community have had Plastibéton Inc. and Francon manufacture a variety of ornamental resin concrete structures for the city. Figure 70 shows a flower box with a ribbed surface and metal clamps. Among Plastibéton's other accomplishments are benches and counters for Barbados Airport.

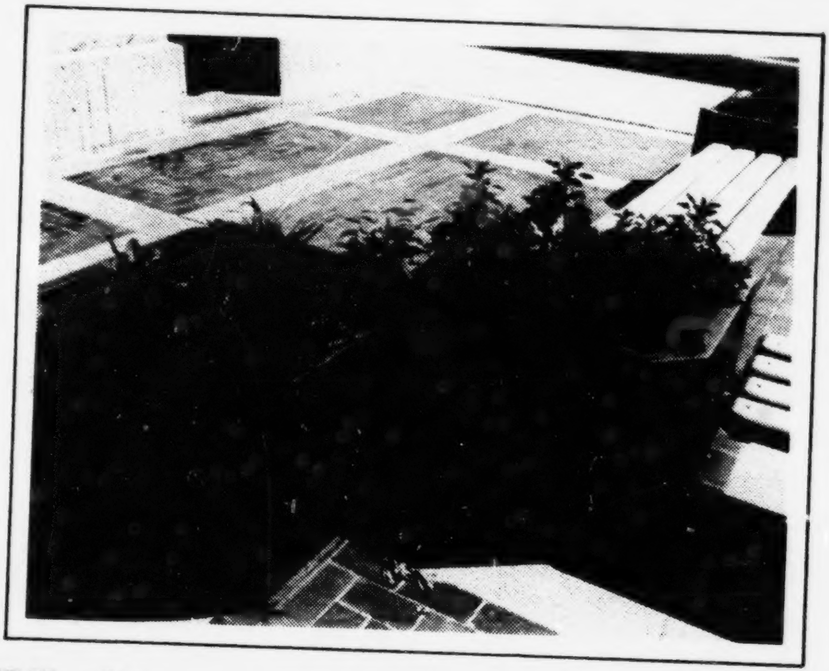


FIGURE 70: Resin concrete flower boxes constructed by Francon for the Metropolitan Transit Bureau of the Montreal Urban Community

9.1.4 Protection against electrical hazards

A Quebec aluminium plant has put down a floor of prefabricated slabs leading out of the rooms containing the electrolytic vats for the purpose of protecting the workers against electrical hazards.

In addition, Quebec Hydro uses resin concrete conduits for electric cables when constructing its substations. Compared with their prefabricated concrete counterparts, these conduits are stronger and their impermeability ensures good dielectric properties.

9.1.5 Protection against abrasion and corrosion of bridge columns

Janin Construction has manufactured resin concrete panels for covering the columns of a bridge on the Magdalen Islands in Quebec. The bridge spans a sea arm and the action of the saltwater and ice had eroded the existing concrete. Repair was effected in three steps. First, the deteriorated concrete was removed. Next, attachments were fixed to the remaining concrete to anchor the resin concrete panels. New reinforcement was erected and the resin concrete panels were used as permanent shutters for holding new concrete poured between them and the healthy concrete. This work was carried out for the Quebec Ministry of Transportation in 1981 (see Figure 71).

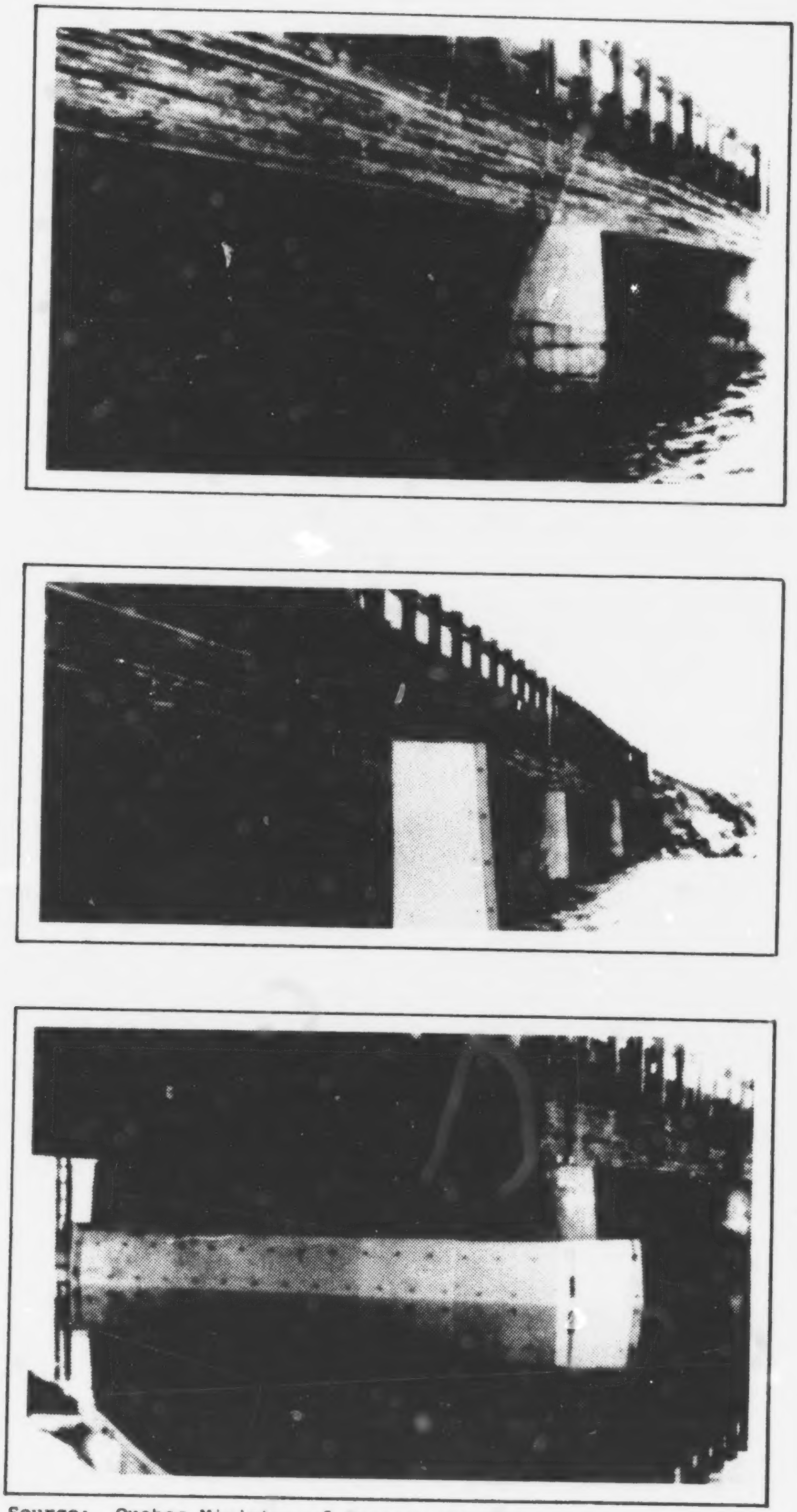
9.1.6 Utilization for expressways

Traffic safety barriers

Large-scale use of de-icing salt for road maintenance in Quebec began around 1960. Salt penetrating into the concrete accelerates degradation of the concrete and corrosion of the steel reinforcing. After about ten years' exposure to freeze-thaw conditions combined with de-icing salt, concrete deteriorates rapidly although such deterioration depends on the severity of conditions and the initial quality of the concrete.

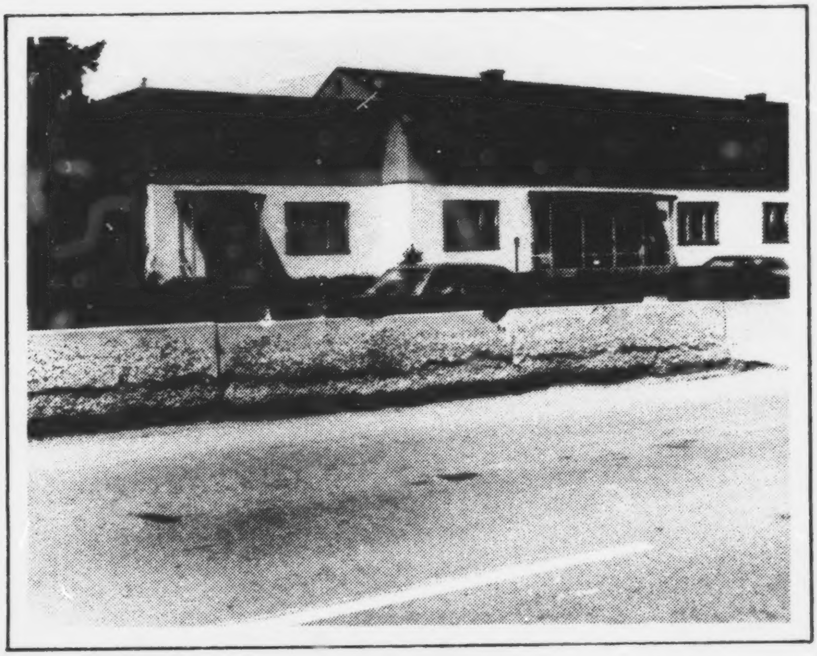
Traffic safety barriers and prefabricated concrete median strips are good examples of concrete that is subject to the destructive action of de-icing salt. Figure 72 shows concrete barriers after some ten years of exposure in the Quebec City area.

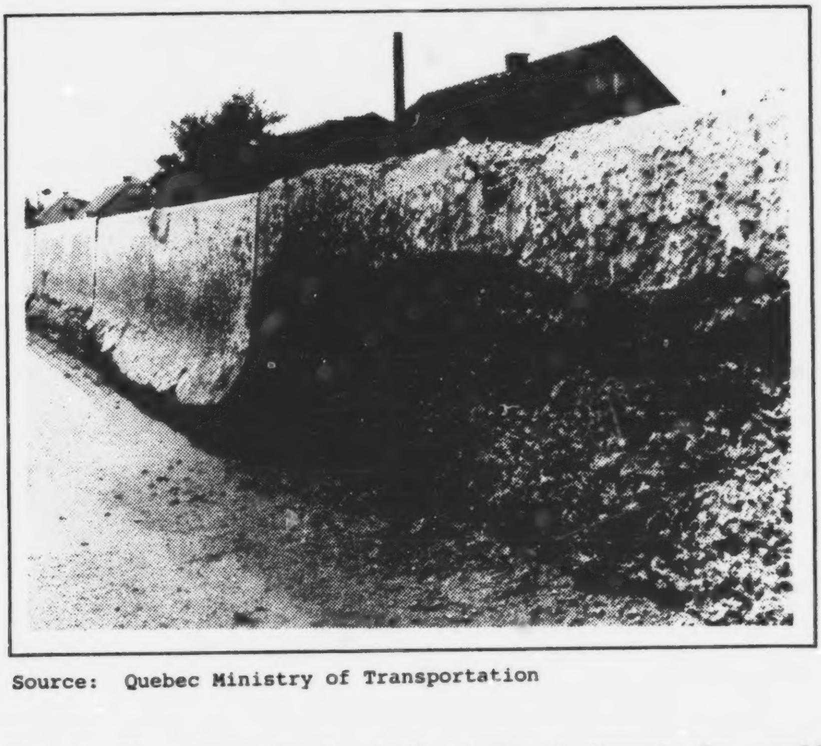
In 1978, the Quebec Ministry of Transportation experimented with 500 feet of a new type of traffic safety barrier. It was extended by 3 1/2 miles in 1979. The barrier came in prefabricated 20 feet sections consisting of portland cement concrete cast inside a resin concrete jacket. The product is manufactured by Plastibéton Inc. (see Figure 73).



Source: Quebec Ministry of Transportation

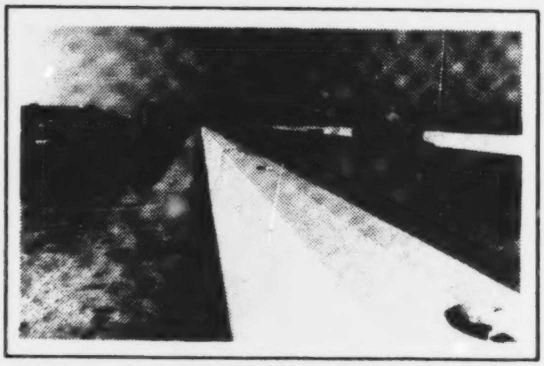
FIGURE 71: Repair of bridge columns in the Magdalen Islands, Quebec





Source: Quebec Ministry of Transportation

FIGURE 72: Traffic safety barrier badly damaged through the combined effects of freeze-thaw activity and de-icing salt (Sainte-Foy, Quebec)



Source: Plastibéton Inc. documentation
(Montreal, Quebec)

FIGURE 73: Resin concrete median strip (Metropolitan Boulevard, Montreal, 1979)

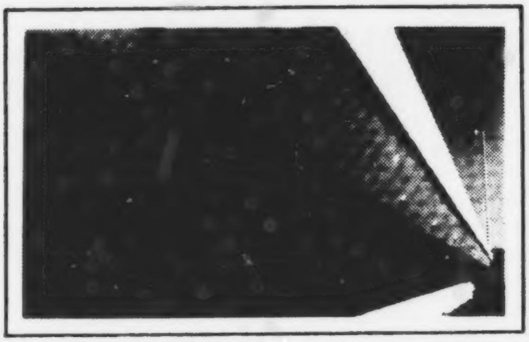
Resin concrete was chosen because the steel reinforcing had to be protected from the destructive action of de-icing salt. The use of resin concrete was no more costly than other methods would have been since repair of the structure required complete or partial replacement of the damaged concrete. Resin concrete was considered most advantageous in terms of cost and protection of the structure.

Generally speaking, these traffic safety barriers stand up well to the environment, although the impact of heavy vehicles has caused some cracks and splintering in certain places. The use of glass fibres in the resin concrete should sufficiently increase its impact resistance, however.

In conclusion it can be said that polymer concrete elements are useful in the protection of concrete, especially in cases where steel reinforcing has to be protected from the environment.

Surface panels for expressways

Repair work on the raised section of Metropolitan Boulevard had resulted in very uneven lateral surfaces. To preserve its aesthetic appearance, curved panels in 17-foot-long sections were placed onto the lateral surfaces. The panels are one inch thick and polymer concrete was chosen for this application on account of its cost and durability without adding excessive weight to the structure (see Figure 74).



Source: Plastibéton Inc. documentation
(Montreal, Quebec)

FIGURE 74: Curved panels used on the lateral surfaces of Metropolitan Boulevard (Montreal, 1977).

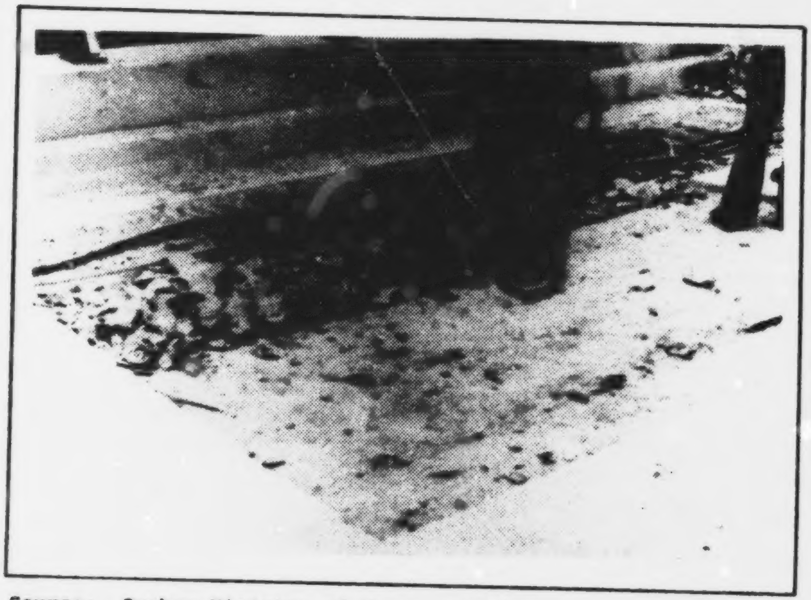
Repair of potholes

After taking note of the work performed in the United States on the repair of concrete road surfaces using resin concrete, the Quebec Ministry of Transportation developed a 14% polyester concrete formulation prepared from readily available aggregates and sand. The concrete would develop a force of 4 000 lb/sq. in. after 2 hours with minimum shrinkage to ensure good adhesion to the existing concrete.

Resin concrete has proved to be advantageous for the repair of heavily trafficked highways and bridges for the following reasons:

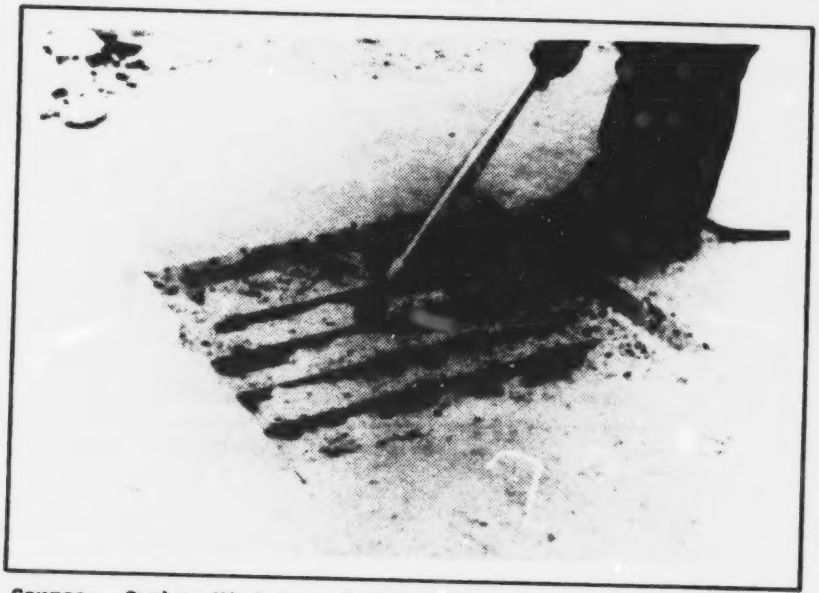
- rapid setting reduces the period of traffic interruption, avoids vibration problems on heavily trafficked roads and reduces repair time;
- the cost of raw materials is less than in the case of commercial preparations of quick-setting premixed concrete.

Figures 75 to 78 illustrate the various steps in road surface repair. As indicated by Figures 75 and 76, this method is used for both large-scale and small-scale repair.



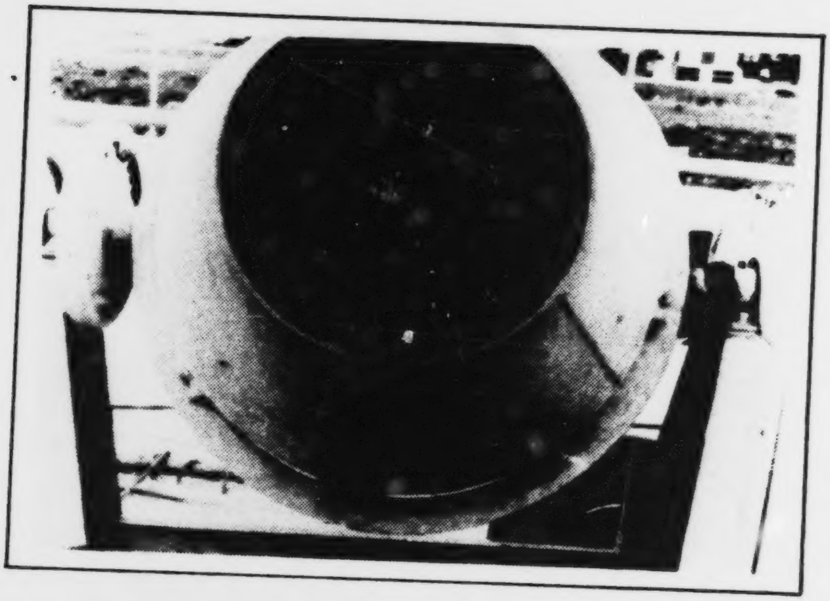
Source: Quebec Ministry of Transportation

FIGURE 75: The surface to be repaired is cleaned right down to the unspoiled concrete



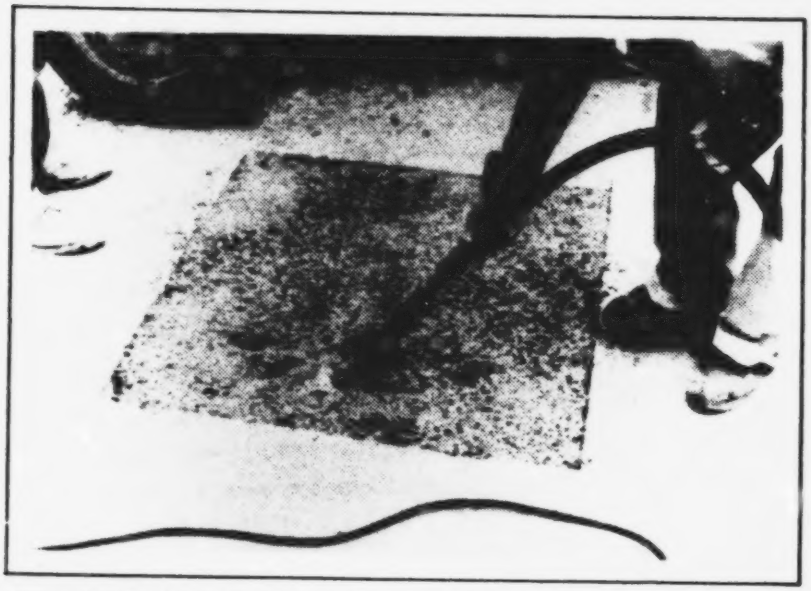
Source: Quebec Ministry of Transportation

FIGURE 76: The surface is dried



Source: Quebec Ministry of Transportation

FIGURE 77: The resin concrete is mixed and placed



Source: Quebec Ministry of Transportation

FIGURE 78: The concrete is compacted my means of vibration to ensure proper blending

9.2 Polymer-impregnated concrete (PIC)

Canadian PIC products are very limited. The Canadian focus has been on the use of PIC by certain consulting engineers for the repair of floors, dams and building structures.

In addition, some research work on impregnated concrete has been carried out at National Research Council Canada and at a number of Canadian universities. This work was concerned mainly with the impregnation of concrete with sulphur and the use of sulphur as a binder to replace cement. There do not, however, seem to be prefabricated PIC products in Canada.

9.3 Polymer-portland cement concrete (PPCC)

PPCC is used mainly for repair work. Epoxy PPCC is used principally for structural repairs while latex PPCC serves' for protective coverings or various applications requiring adhesive properties (e.g. roughcasts of building foundations and prefabricated brick panels). The fields of application are: industrial floors, expressway, parking lot, bridge and dam repair, and the repair of defects in the design and construction of concrete structures.

These products are manufactured by companies specializing in epoxy resin and polymer emulsion products or by enterprises that supply additives for cement concrete.

Canadian manufacturers include the following companies:

- Sternson, Brantford (Ontario)
- Chemor, Montreal (Quebec)
- H.B. Fuller Canada Inc., Montreal (Quebec)
- Kamma Polymers Ltd, Calgary (Alberta)
- Taget Concrete Products, Vancouver (British Columbia)
- Gemite, Toronto (Ontario)

- Sika Canada, Montreal (Quebec)
- FRC Composites Ltd, Toronto (Ontario)
- Blachford Ltd, Montreal (Quebec)

In addition, a number of American-made products are used in Canada. The two main American companies in this field are Sika and Adhesive Engineering Co. Their products are sold by local distributors and installed by various contractors.

9.4 Canadian products and uses: conclusion

Resin concrete

The construction industry was the first sector in Canada to utilize resin concrete - mainly in the form of panels. The plastic potential of the material for casting three-dimensional products has begun to be utilized, although its aesthetic possibilities (shapes, colours and textures) have not yet been fully exploited for Canadian applications.

The few experiments that have been conducted on the application of resin concrete for expressway construction and repair have shown that this material can be used profitably in Canada.

The use of resin concrete for the manufacture of industrial products is just beginning in Canada and is slated to expand.

The commercial use of PIC in Canada seems to be limited to structural concrete repairs. PPCC, however, is a greater commercial success than PIC, having been used for a number of years now for repair work on account of its adhesive properties. Moreover, Canadian manufacturers produce many different products for a variety of applications.

10.0 SAMPLE SURVEY OF MANUFACTURERS AND USERS OF RESIN CONCRETE PRODUCTS

The purpose of examining the situation in Canada, besides bringing to light some of the typical products, was to identify research and development needs and the factors hampering the development of polymer concrete in Canada. A representative sampling of the various sectors concerned were thus polled or contacted.

Manufacturers of synthetic marble and resin concrete products were contacted for their views on R&D needs.

Two hundred and fifty of the major Canadian consulting engineering firms were polled for their opinions since they probably constitute the most important group of potential users.

Users from a variety of sectors were contacted to ascertain how they felt about the situation and to distinguish problems or constraints that impede the development of resin concrete products.

10.1 Survey conducted within the synthetic marble industry

This survey, which uses a representative sampling of the Canadian synthetic marble industry, was conducted in June 1982. The list of respondents was prepared on the basis of addresses of synthetic marble manufacturers obtained from:

- Government of Canada - Industry, Trade and Commerce, Plastics, Rubber and Chemical Specialties Division
  Mr B. Labelle

- Répertoire des produits fabriqués au Québec, Centre de recherche industrielle du Québec, 5th edition

- Fraser's Canadian Trade Directory, 69th edition, 1982

- Telephone directories of Montreal, Ottawa and Toronto.

The list of respondents was found to include a number of companies that were no longer operating.

All in all, 81 questionnaires were sent off and 15 of these were returned completed. Allowing for the fact that 31 questionnaires did not reach their destination owing to an incorrect address, the proportion of replies is around 30%. This compares with the average rate of 25% obtained for various polls conducted in the industrial sector by mail.

The aim of the questionnaire reproduced in Appendix 1 was to identify the research and development needs of manufacturers in this sector.

Table 24 gives an overview of the information gathered from the questionnaires, including a synthesis of the remarks made by the respondents. The following facts about the synthetic marble industry emerge from the table:

- The respondents represent the Canadian industry fairly well.
- Over half of the respondents classify themselves as small businesses (1 to 5 employees). Five enterprises, or 30%, have over 10 employees.
- The respondents produce almost nothing but bathroom products, and, with two exceptions, production is manual.
- Know-how comes mainly from the suppliers. Despite their size, some companies conduct R&D activities. It is interesting to note that R&D is carried out by the two enterprises with automated production.

TABLE 24: Results of the survey conducted within the synthetic marble industry

ENTERPRISE		NUMBER	MARBLE PRODUCTS								PRODUCTION			ORIGIN OF KNOW-HOW			RESEARCH AND DEVELOPMENT NEEDS														
																	RAW MATERIALS					PRODUCTION METHOD			PRODUCTS					
																			GEL COAT PROVIDES MORE PROTECTION AGAINST											
NUMBER	PROVINCE	EMPLOYEES	BATHROOM PRODUCTS	SINKS	WALL PANELS	BATH	COUNTER TOPS	TABLES	CUSTOM-MADE PRODUCTS	OTHER ...	MANUAL	AUTOMATED	MAKES ITS OWN MOULDS: YES, NO	RESEARCH	LICENCE-AGREEMENT	SUPPLIERS	COST REDUCTION	REDUCTION IN QUANTITY OF RESIN USED	SCRATCHING	DISCOLORATION	ELIMINATION OF GEL COAT	AUTOMATED EQUIPMENT	REDUCTION IN NUMBER OF STAGES	MORE QUALITY MOULDS	INCREASED RESISTANCE TO THERMAL SHOCK	REDUCED WEIGHT	WOULD A 10-15% WEIGHT INCREASE BE HARMFUL?	IMPROVED MECHANICAL PROPERTIES	FRP - SYNTHETIC MARBLE COMPOSITE	REMARKS
1	QUE	5	X		X	X					X		N	X		X	X	X	X				X		X	X	N		X	A
2	QUE	2									X		N			X		X	X		X				X		N			B
3	QUE	12		X	X		X	X			X		N	X		X	X	X	X						X	X	N			C
4	ONT	12	X								X	X	N	X				X		X		X		X			N			D
5	ONT	6			X		X				X		N	X	X	X	X	X				X			X	X	Y			-
6	ONT	3			X		X	X			X		Y			X		X	X						X		Y	X		E
7	ONT	[illegible]	X	X	X	X	X				X		N			X	X	X	X						X	X	Y			F
8	ONT	1.5			X		X			X	X		-			X	X			X		X		X	X		-			G
9	ONT	11	X		X			X		X	X	X	Y	X	X		X	X		X		X	X				Y			H
10	ONT	2		X							X		N			X	X	X									Y			-
11	MAN	20-40			X	X	X				X		Y				X	X							X		Y			-
12	SASK	2								X	X		-				X									X	-			-
13	B.C.	6	X	X	X						X		Y				X	X		X					X		Y			-
14	B.C.	5-19	X			X	X				X		N				X	X						X	X		Y			-

TABLE 24: Results of survey conducted within the synthetic marble industry (cont'd): Comments from respondents

A) Although the market for synthetic marble products is expanding, these products are new and generally not sufficiently known. Potential is seen for new products in various fields of application.

B) The development of new resins such as those with improved properties that are used for Dupont's Corian products could possibly eliminate the need for gel coats. Owing to the absence of competition, Dupon is not conducting research on this product.

C) If production costs can be reduced and gel coat strength improved, the future of this type of concrete looks very promissing.

D) The market for polymer concrete is in new products for industry, transportation, agriculture and highway construction.

E) Increasing the competitiveness of synthetic marble implies and increase in the volume of production resulting from a better appreciation of synthetic marble by the public, provided its two weaknesses are corrected:

- synthetic marble is structurally weak - giving rise to problems of cracking
- gel coat does not wear well enough.

Little research has been done on the subject in the past 15 years. To be competitive, synthetic marble products must offer quality matching their price and possess long-term properties more comparable with those of porcelain.

The present synthetic marble industry is composed of small workshops that do not carry out R&D and cannot exert pressure on suppliers who do little or no R&D. The main product, viz, bathroom sinks, is for luxury homes. New products have to be developed to give this industry a lift.

Certain applications such as sewage pipes for industries and laboratories, manholes, crematoriums and monuments could give the resin concrete market a boost.
The development of these products, however, requires the financial resources of larger businesses.

F) The producer must perform quality control on resins purchased.

In addition, an economical system of protecting baths during storage, handling and, above all, installation would be very useful.

Synthetic marble products for the bathroom are in demand for renovated and luxury homes and condominiums. There is a large potential market for 3/8" to 3/4"-thick panels in the commercial and public construction sectors, however, if their fire resistance and insulating properties can be demonstrated.

G) There must be a future for resin concrete in the construction of building facades, stairs, docks, etc.

H) The greatest reduction in production costs is had by using a reliable automatic machine that has lasting quality and can be regulated. (The Venus is not entirely satisfactory).

The use of automated machinery in this industry will:
- reduce the number of manufacturers
- increase the quality of products manufactured
- increase R&D and the range of products manufactured.

This company is following developments in resin concrete in Europe and is waiting for a suitable moment to product the material. The current constraints on the resin concrete market are marketing and R&D.

The research and development needs expressed by the companies were divided into three categories: raw materials, production methods and products. The following trends can be identified:

Raw materials

- Reducing the quantity of resin and production costs is a preoccupation shared by almost all respondents.
- Improving the gel coat's resistance to the atmosphere is a concern of over half of the respondents and 4 of the 5 businesses carrying out R&D.
- Another major concern is improving resistance to thermal shock.

An increase in thermal shock resistance would probably require improvement of the resin formulations used. Similarly, improving the performance of existing gel coats would require expertise and R&D work with respect to resins and resin mixtures. The cost of such work is not within the means of companies in this sector, however.

Production method

Using a continuous mixer to manufacture synthetic marble products reduces labour and resin costs. The majority of Canadian producers do not use continuous mixers, however, since the investment would be too great for most of them. In the short term, changes in resin formulations can bring about a reduction in costs and in the quantity of resin used.

Products

Reducing the resin-aggregate ratio would increase the weight of the products, which does not seem desirable according to most of the respondents. The use of various types of light aggregate may solve the weight problems, however. The development of synthetic marble / glass fibre composite structures could also reduce the thickness of the walls and the weight of the prefabricated sections while at the same time improving their mechanical strength.

If the present market is to expand, the performance of existing synthetic marble products must be improved so that they can compete successfully with ceramic and other materials. That is why it is so important to improve the properties of these products. In addition, wall products must be developed to give this industry a lift. Unfortunately, manufacturers have few resources to invest in R&D projects and suppliers have halted the development of their products.

10.2 Views of manufacturers of resin concrete products

Four companies that manufacture or have manufactured resin concrete products were contacted. In addition, interest in resin concrete was shown in a variety of ways by quite a number of enterprises in the prefabricated concrete industry. Of these, four companies were contacted who were interested in resin concrete production or had already performed R&D work or produced prototypes.

The main points or those mentioned most frequently are, grouped by subject:

Production cost

- Polymer concrete is expensive because of the need to use batch production methods in a market dominated by one or two producers.

- "To ensure that the material is remunerative and that it has a wide range of applications, its possibilities must be monitored. This means mass production, a short casting time and a rapid casting cycle".

Market

- Users are interested in the price first and the quality second. To replace existing materials, products must have competitive prices, even if they are of a better quality.
- Its remarkable freeze-thaw durability is one of the main reasons why polymer concrete should be able to penetrate the Canadian market in construction, roads, bridges, etc. There is a great market for polymer concrete with competitive prices.
- The various materials have various fields of optimal application according to their properties and costs.
- There will be a market for resin concrete products wherever regular concrete does not fully satisfy the requirements concerned or products cannot be made with regular concrete.
- Demand would come mainly from public bodies such as the Ministry of Transportation, Quebec Hydro (for conduits), the chemical industry and city corporations (street furniture, etc.).

Research and Development needs

- Owing to the phenomenon of shrinkage during resin concrete casting, steel reinforcement is not appropriate and would cause cracks. Glass fibre is the most suitable means of reinforcement but it is expensive. R&D efforts should be directed toward finding economical ways of reinforcing resin concrete.

- Studies on resin concrete performance and on methods of resin concrete reinforcement by means of pultruded glass fibre rods.

- Determination over a 4 to 5 year period of the mechanical properties and chemical resistance of loaded plastics such as resin concrete submitted to corrosive substances (acids, alkalis, etc.), high temperatures (200°F - 300°F) and the effects of pressure and an electric field of 20 000 amperes in industrial environments.

- Determination of properties according to the resin concrete formulation (quantity and type of resin).

- Development of resin formulations for specific industrial applications (corrosion, temperature, etc.) and determination of the properties obtained.

- The development of methods, formulations and tests should not be done only at the laboratory level but also in pilot plants so that factory production problems can be discovered and R&D can be directed toward solving practical industrial production problems.

- Assessment of long-term action of the sun on colours and resin.

- Continuous production equipment currently on the market is either too slow (Venus) or too costly (Respecta). At present, the Canadian market makes it difficult to invest 200 000 $ in an automatic machine. Components already existing in other types of mixer could be used to produce less expensive machinery.

- Since the production technique has been fairly well perfected, research should focus on the development of new products or new applications to expand the market for the products.

New products

- The development of new products using resin concrete and light aggregates offers great potential for many products.

- The time is not yet ripe for launching new products, especially if they are more expensive than those they are meant to replace in spite of being more durable.

Information

- Familiarity on the part of potential users (architects and engineers) with the characteristics of the products and the advantages they offer for various applications is essential if new uses are to be developed. Engineers know that resin concrete exists but they know little about its characteristics and they cannot therefore use it in situations where advantage could be taken of its properties to develop new products or deal with existing problems.

- Users must be informed about the properties of resin concrete and the relationship between cost and performance. Not only should the initial cost be considered, but so also should the life of the materials compared. In addition, other advantages connected with the use of resin concrete should be brought out.

- Those inviting tenders are not sufficiently acquainted with the specifications required for resin concrete products. The development of these specifications, however, and the research and tests that have to be carried out for the purpose, should not be left solely to the manufacturers.

- Resin suppliers have little understanding of resin concrete. To give an example, a manufacturer stated that his technical knowledge came from published material and 20 years' experience in the formulation of resins.

- Some users (architects), having little knowledge of the production requirements of this material, request production in small batches which involves high unit costs.

10.3 Opinion of users

Users from various sectors were contacted. They comprised consulting engineers, architects and other users from government and industry alike. Those who were considered most useful for the purposes of the survey were contacted by telephone and some were visited.

10.3.1 Survey conducted among Canadian consulting engineering firms

This survey, which was carried out in June 1982, involved members of the Association of Consulting Engineers of Canada. Firms specializing in the areas of architectural engineering, construction technology (including materials), etc. were polled. A total of 250 questionnaires were sent throughout Canada, to addresses constituting a representative sampling of Canadian consulting engineers. Appendix 2 contains a sample of the questionnaire used.

The purpose of the poll was:

- to establish a list of Canadian expertise in these areas, including projects accomplished (questions 5 and 8);
- to evaluate the level of knowledge of polymer concrete (PC, PIC and PPCC) on the part of users (questions 3 and 4);
- to identify the main constraints impeding the development of these materials (question 6);
- to collect user views on market potential and R&D needs (question 7).

Table 25 shows the level of knowledge of the respondents.

TABLE 25: Regional distribution of consulting engineers and their degree of familiarity with PC, PIC and PPCC

DISTRIBUTION		DEGREE OF FAMILIARITY			
PROVINCES	NUMBER OF REPLIES	VERY LOW	TECHNICAL OR COMMERCIAL PUBLICATIONS	STUDYING THE POSSIBILITY OF USING THESE MATERIALS	KNOWLEDGE APPLIED TO PROJECTS
Atlantic	2	-	2	-	-
Quebec	26	1	12	10	3
Ontario	13	1	8	3	1
Prairie	12	1	8	-	3
Br. Columbia	9	2	2	1	4
TOTAL	62	5	32	14	11
PERCENTAGE	100%	60%		40%	

What strikes one immediately is that only 11 of the 62 respondents have used these materials. Indeed, the majority of these firms do not have a sound knowledge of resin concrete products since only 40% have so far used them or studied the possibility of using them.

Table 26 gives the reasons why most of the firms contacted had never used polymer concrete. The chief reason was ignorance regarding the effective use of the material. Seventy percent of the respondents stated that they were ill-informed concerning the potential of resin concrete. The two other reasons given were, in descending order, inability to find a useful application and the high cost of the material.

TABLE 26: Reasons given by consulting engineers for not using polymer concrete (PC, PIC and PPCC)

REPLIES		NUMBER OF RESPONDENTS	PERCENTAGE OF RESPONDENTS
LACK OF KNOWLEDGE	- Lack of knowledge of materials	36	70%
	- No knowledge of performance of material for the application considered		
	- Absence of specific standards concerning these materials		
MISCELLANEOUS	- Inability to find a useful application	17	33%
	- High cost of materials	11	22%
	- Products not sufficiently available commercially	6	12%
	- Other	2	4%

It is interesting to note that 80% of those who stated that cost had been a limiting factor in the use of the concrete, also said they were ill-informed on the subject.

Virtually all the respondents indicated their interest in consulting a document that would list existing structures and products in which polymer concrete has been used.

The types of project implemented by the consulting engineers who were polled are given in Table 27. Only about ten firms stated they had already used

TABLE 27: Polymer concrete projects implemented by Canadian consulting engineers

NO	PROVINCE	PROJECTS IMPLEMENTED	MARKET	COMMENTS
1	B.C.	Repair: Industrial floor (PIC) - (MMA) : Floor of tenement house (PPCC) : Concrete slabs with and without fibre (PPCC) : Section of highway (because of freeze-thaw durability) (PPCC) : Repair of worn-out floor (PC) - (MMA)	Mainly for the repair of concrete structures: «Many structures and works throughout the country, especially in British Columbia, have reached the stage where they need to be repaired or replaced».	
2	ONT.	Repair: Delaminated concrete (PIC) : Bridge deck (PPCC)	. Repair of concrete where replacement is not feasible. . Concrete covering on surfaces other than slabs. . Prefabricated section of thin concrete.	
3	QUE.	Covering the lateral surfaces of the raised section of Metropolitan Boulevard, Montreal (PC)	Could replace conventional concrete in many applications.	A handbook on polymer concrete as a structural material would help to develop this market.
4	QUE.	Repair: Underwater hydraulic works (PC) - (Epoxy) : Dam (PPCC - prepared latex) : Fly ash silo (PPCC - prepared latex) : Columns and piers	. For small prefabricated PIC sections because in situ use is difficult with these structures. . For portions of hydraulic structures such as spillways, where protection against corrosion and abrasion is required, and for bridge decks, parking lots, curbs, etc., which require protection against de-icing salt.	
5	QUE.	Concrete repair: Sealing and levelling (PC)		
6	ALTA	Expressway repair (PC)		Definitely require much more technical knowledge on how to use it ...
7	MAN.	Repair of concrete structures/works (PIC)		Need for more technical information on performance, properties, application methods...and cost.

TABLE 27: Polymer concrete projects implemented by Canadian consulting engineers (cont'd)

NO	PROVINCE	PROJECTS IMPLEMENTED	MARKET	COMMENTS
8	B.C.	Covering for industrial floors, chemical and food industries; mortar (PC)	. Protective covering for portland cement in aggressive environments. . Repair of reinforced concrete and masonry structures.	
9	B.C.	Repair work on roads and bridges - with resin concrete and mortar (PC)	. Facing panels for tall buildings. . Repair of exposed concrete (bridges, etc.).	
10	ALTA	Floor coat (PC)	. The greatly increased durability, flexibility and adhesion and the great flexural strength of PC favour its use as bridge decks and road surfaces and for stucco on walls. . PIC could be used for sewage pipes, prefabricated railway sleepers, etc. since surface impregnation would provide good protection, though the cost of production is a disadvantage.	
11	B.C.	Structural repair of a building (PC)	Mainly for repair work and probably to increase freeze-thaw durability when PC is not used in combination with hydraulic concrete.	Experience with resin mortar (Colma-Dur) between 1970 and 1980 has shown that this product is effective only for interior repairs.
12	MAN.	Repairs using PPCC	Construction of industrial floors and repair of floors damaged by salt. There is a good market for concrete parking lot repair. Market potential for the construction and repair of boat decks and marine structure is excellent.	

PC, PIC or PPCC in the repair of concrete structures and works such as industrial floors, expressways, bridges, bridge columns and hydraulic works.

The fields of application which the consulting engineers foresee for these products relate mainly to concrete repair and protection. Since they are involved chiefly in concrete construction and repair, few of them mentioned the possibility of using prefabricated products.

Even those who have already used polymer concrete deplore the lack of information on the subject. This confirms the need to provide potential users (architects, engineers, builders, designers, etc.) with more information if we want to promote effective use of this material, especially in a difficult climate like that in Canada. Indeed, use of polymer concrete without an adequate understanding of its behaviour compared with portland cement concrete can in some cases lead to incorrect usage as indicated by certain examples from technical literature. (57 & 58)

Table 28 indicates the research needs expressed by the consulting engineers.

TABLE 28: R&D areas identified by consulting engineering firms

Development of effective concrete repair techniques using PC, PIC and PPCC.

Research to reduce the quantity of PC in its applications so as to out the cost; prefabricated PC sections.

Reduction in cost of production.

Aging of PPCC and its impact resistance.

Systematic research program to ascertain the behaviour of these materials, after reviewing the information already available.

The poll did not bring to light many new Canadian manufacturers of products belonging to the three types of polymer concrete.

It was therefore considered expedient to apply for information from the main Canadian organizations connected with polymer concrete (over a hundred of them):

- national and provincial associations in the fields of construction, engineering, concrete and architecture;
- Canadian university faculties of civil engineering and architecture;
- provincial research laboratories.

No additional interest was revealed, however, which would seem to prove that Canadian expertise in this field is limited both in the manufacturing sector and among the consulting engineers.

10.3.2 Views of other users

Architects

Even though thousands of construction projects in the United States have used resin concrete, Canadian architects seem to know very little about this material and its possibilities. Some companies that have had experience with the material were contacted, however. They mentioned the following main points:

- Polymer concrete was used mainly because it is easy to maintain (graffiti can be easily removed), has good potential in terms of shapes and colours (according to the Metropolitan Transit Bureau of the Montreal Urban Community) and has great strength and many useful properties, mechanical and aesthetic, for exterior construction (according to Bureau B.B.G. et Associés of Quebec City).

- Resin concrete can compete effectively with reinforced plastic (FRP) panels for construction; it is less costly, stronger and offers just as many shapes and colours.

- Users and architects in particular, need to know the potential and limitations of the material and the effect that non-repeat dimensions have on costs. If the cost of the moulds has to be written off over a period that is too short, we get higher unit costs.

- Resin concrete is a good product. The lack of knowledge regarding its behaviour in the field, however, puts the architect at a disadvantage since he would be taking a risk by specifying it in his designs. This lack of knowledge relates specifically to:

  . adhesion between different materials;
  . dimensional stability of panels once they are installed;
  . colourfastness.

- Having standards and performance specifications for polymer concrete construction materials would facilitate the task of architects while guaranteeing consistent minimum quality.

- Some say that the unit cost should be much the same as the price of portland cement concrete while others maintain that polymer concrete's superior properties justify a higher price.

- Besides being used for facing panels, polymer concrete could be utilized for the impermeabilization and repair of roofs. The development of lightweight panels and oxidized resin (e.g. gunite) could lead to new applications for construction.

Other industrial or government users

Generally speaking, users are very satisfied with the material - which does not exclude some small problems encoutered through lack of knowledge and experience on the part of new companies starting this type of production.

11.0 MARKET POTENTIAL FOR CERTAIN USES OF PC, PIC AND PPCC

There is very little data on which to assess the Canadian market for resin concrete, impregnated concrete and polymer-portland cement concrete products. In most cases, this information is kept confidential by the various manufacturers and suppliers. What we can do, however, is estimate the potential market on the basis of some typical applications of polymer concrete.

11.1 Repair and maintenance of concrete roads, bridges and viaducts

According to Mr D.W. Fowler, Chairman of Committee 548 ("Polymers in Concrete") of the American Concrete Institute, there is an enormous market for the repair of concrete bridges and viaducts in the United States. In fact, about 100 000 bridges and viaducts are in need of repair. (20 & 47) While, on the face of it, this may seem surprising, it is confirmed (47) by the fact that in 1981 highway infrastructure repair and maintenance costs exceeded the cost of new construction projects (48) - a phenomenon that had not been seen since 1957. This can be explained by the fact that the United States has a relatively old highway network which will require more and more maintenance in the future.

Even though the Canadian highway network is newer and less developed than that of our neighbours, it is subject to more rigorous freeze-thaw conditions and each winter suffers the effects of the large-scale use of de-icing salt. Recent statistics from Statistics Canada show that around 100 million dollars are spent annually on bridge and viaduct repair. This sum represents about 20% of the overall amount for the "new construction and repair" category.

PC, PIC and PPCC can be used for highway and bridge repair work. Of the three, PPCC currently seems to be the most popular for this type of work in Canada. PC is not known very well in this field of application and PIC, besides not being well known, would be more costly owing to its complicated method of application.

11.2 Street curbs

Street curbs are currently made of granite. In 1979, Quebec manufacturers of prefabricated granite produced 2,2 million dollars worth of street curbs. This represents about a quarter of all curb production in Canada. Thus, the Canadian market for granite curbs can be estimated at around 9 million dollars.

In 1979, the Association des producteurs de granite du Québec sold approximately 325 000 linear feet of curb for 1,5 million dollars, or 10% of the total Canadian prefabricated curb market.

Because of the better properties of granite compared with concrete (mechanical strength, resistance to salt, etc.), granite curbs have a four times longer life than their prefabricated concrete counterparts would have. An economic study prepared for the Quebec Ministry of Transportation showed that granite curbs, although 25% more expensive, were more than three times more economical than prefabricated concrete curbs, bearing in mind that life expectancy is over 60 years. (49)

The use of polymer-impregnated concrete and resin concrete offers just as many advantages as granite does, but, owing to a lack of data on the life of PC and PIC in this type of application, we cannot properly assess the competitive potential of these materials on the market.

11.3 Electric insulators

In the United States, the annual market for ceramic insulators for electric power transmission is in the order of 500 million dollars. (27) Around 14 million dollars worth of these products were imported into Canada in 1980, and this figure jumped to 23 million dollars in 1981. There has also been some Canadian production of ceramic insulators but statistics are confidential because of the small number of manufacturers.

Electric insulators made of resin concrete are still at the developmental stage and tests on electric power lines are currently being carried out.

Another potentially attractive market for resin concrete which is currently being tested is underground conduits for high tension power lines. This would greatly reduce the cost of erecting power lines in urban areas while at the same time preserving the environment.

11.4 Industrial products

Given the diversity of available products and the absence of valid statistics, it is difficult to make an exact assessment of the market for polymer concrete industrial products. We do have the following information, however:

- In the USSR, polymer concrete is used in nonferous metal refineries to produce slabs, columns, machine bases and electrolytic vats. By using resin concrete electrolytic vats it has been possible to do away with various types of protective covering (lead, graphite, etc.), to reduce power consumption by decreasing leakage currents and to cut labour by 5 to 12 times on account of the durability of the vats. The volume of resin concrete used in this industrial sector is in excess of 20 000 cm^3. (51)

- Resin concrete is also used in many other industrial sectors in the USSR. Applications include steel pickling baths, pipes and headers of varying diameters, tanks, settling tanks and headers for the production of sulphuric acid, grates for cattle raising farms, protective covering for irrigation dams, etc. The company Respecta, the principal manufacturer of continuous resin concrete mixers, stated that the USSR was its main client.

- In Japan, the Nippon Telephone and Telegraph Public Corporation produced over 40 000 manholes of various sizes between 1971 and 1977. Annual production in 1978 was 20 000 tonnes. In addition, four companies annually produce 30 000 tonnes of resin concrete pipes between them. Annual consumption of PPCC is approximately 70 000 tonnes. (16)

- In the USA, four enterprises currently possess continuous resin concrete production machinery (Respecta). Each machine has an annual production capacity of 1 million lbs of resin concrete. The production capacity of manufacturers using batch production methods and those using the Venus machine is not known.

- Since 1980, Plastibéton Inc. has produced 55 000 linear feet of resin concrete surface conduits for control cables used in Quebec Hydro's distribution substations. These conduits are non-conducting, impermeable and lighter and stronger than their concrete counterparts.

- Metropolitan Boulevard in Montreal probably represents the most important application of resin concrete in Canada with its resin concrete lateral panels and over 3 1/2 miles of resin concrete median strip.

- The market for resin concrete industrial products is expanding.

11.5 Facing panels (curtain walls)

In 1979, Canadian production of concrete panels was estimated at 96 million dollars, Quebec being responsible for 20 million dollars of this sum. In the same year the companies belonging to the "Association québécoise des producteurs de granite" sold 6 million dollars worth of these products.

The properties of correctly formulated resin concrete are akin to those of granite and its aesthetic qualities are more attractive. Its price, however, is between that of regular concrete and granite. If resin concrete were better known, one might suppose that its market would be somewhere between that of its two competitors.

The Architectural Research Corporation is probably the oldest company in the United States operating in prefabricated resin concrete panels. Since 1959, it has implemented thousands of construction projets using resin concrete panels.

The resin matrix in these panels is composed of a polyester - methyl methacrylate resin mixture. According to the Corporation, this type of application represented, in 1974, a market amounting to some 6 million dollars and a market for resins estimated at about 3 600 tonnes. (6 & 50)

Despite a decline in the economy, a 30 to 40 million dollars market was predicted for these products in the United States in 1980.

11.6 Synthetic marble

The major manufacturers of synthetic marble in Europe use continuous mixers. Respecta has sold its manufacturers over 200 machines with a production capacity of more than 80 000 tonnes of synthetic marble per year.

The United States has 700 to 800 manufacturers of synthetic marble products, while Canada has around sixty. A study published by the Business Communications Co., Stanford, (Connecticut) in 1978 entitled "Polyester Growth Markets" estimated the 1977 consumption of unsaturated thermosetting resins by the American synthetic marble industry to be 210 million lbs. The study predicted an average annual rate of increase of 4% until 1987 and a 310 million lbs consumption of resin in 1987. In view of the fact that this industrial sector is composed primarily of small enterprises both in Canada and in the United States and that the Canadian sector is about one tenth the size of its American counterpart, it is possible to estimate the annual Canadian consumption of thermosetting resins at 10-15 million lbs.

11.7 Other products

Other products not yet manufactured in Canada nevertheless offer market potential. Some examples are:

- The production of resin concrete **tiles or slabs for interior or exterior use.** The products could compete with high quality ceramic tiles for exterior use. The production cost of quality ceramic tiles is around 1,25 - 2,00 $/sq. ft, though the selling price may rise to 6,00 $/sq. ft. According to recent market studies, the consumption of ceramic tiles in the United States is due to increase over the next decade. Annual per capita consumption is 7-8 sq. ft in the United States, 25-30 sq. ft in Italy and 19 sq. ft in Brazil.

  Resin concrete could compete with many existing plastic **conduits or pipes.** PVC pipes over 30 cm in diameter could be produced from resin concrete. Many corrosion-resistant industrial products could eventually be replaced by resin concrete.

- Resin concrete can even be used in cases where stainless steel or cast iron is required. Thus, Diversified Products of Opelika (Alabama) makes weights and counterweights for its exercise bicycles ant its weightlifting equipment out of resin concrete filled with iron filings and scrap metal.

- In the construction industry, new products and new concepts in prefabrication can be had by utilizing the properties of resin concrete (bathrooms, passive solar collectors developed by M.I.T., etc.).

11.8 Conclusion

Although the available information on this subject is somewhat limited, certain conclusions can be drawn:

- The repair of concrete structures such as bridges and viaducts represents a substantial market which is expected to grow in Canada.
- Economic studies comparing the cost and performance of various materials for the same application would help users in their choice of the most economical material for the life of the particular product.
- Certain polymer concrete applications in the field of electricity could constitute major markets in a few years.
- The use of resin concrete in industry is much more advanced in Japan and the USSR than it is in Canada. Nevertheless this sector has good market potential.
- The potential Canadian market for resin concrete facing panels represents millions of dollars a year and this could even increase if the cost of production were reduced.
- Synthetic marble production in Canada would entail an annual consumption of millions of pounds of thermosetting resins.

- Resin concrete products not yet manufactured in Canada, including the development of new products to meet Canadian user needs, constitute another potential market, though it is difficult to give a precise estimate here. In Japan, resin concrete was developed to meet needs encountered in the public utilities sector (telephone services and sewerage) while in the Soviet Union applications were developed for the industrial sector, railways and dams.

PART III

RESEARCH AND DEVELOPMENT OPPORTUNITIES

Polymer concrete materials are still seeing relatively little use in Canada.

The superior properties of the various types of concrete / polymer composite, however, make them attractive materials for various applications, especially in rigorous climates like that in Canada.

Even though this study concludes that, to stimulate development of the Canadian polymer concrete industry, potential users (consulting engineers, architects, designers, etc.) need to be better informed, our most active survey respondents identified many R&D opportunities.

This last part of the study considers resin concrete R&D in a world context and discusses the R&D opportunities from the point of view of support to the Canadian polymer concrete industry.

12.0 RESEARCH AND DEVELOPMENT OPPORTUNITIES

It can be concluded from the information presented in the first part of this study that resin concrete (PC) and polymer-portland cement concrete (PPCC) have reached a level of commercial development. Polymer-impregnated concrete (PIC), for its part, is still at the stage where its performance is being measured or where it is being subjected to pilot studies.

The main commercial applications of the PPCC types are for repair work, while resin concrete types (including synthetic marble products) are used chiefly to make prefabricated products.

As indicated in Table 29, the level and type of application differs from country to country. Even though many products are already being produced commercially, however, many countries are conducting pure and applied research aimed at improving current uses and developing new applications.

12.1 Review of world R&D on polymer concrete

In Japan, pure research on polymer concrete is being carried out in the universities, while public utility companies, who are the biggest users of this new material, have invested a great deal of energy in the development of industrial applications.

In the USSR and the USA, many government laboratories are concerned with polymer concrete. In the USSR, as in the other Communist bloc countries, government research agencies conduct fundamental research as well as studying potential applications. The number or products that have found an industrial application in the USSR testifies to the success of the research.

In the United States, government laboratories focused their attention first on PIC and later on PC products. American research projects are mainly on the level of pure research or pilot applications in the military sector (ultra-rapid

TABLE 29: Development of some uses of resin concrete throughout the world

Level / Type of development	COMMERCIAL		PILOT	LABORATORY
	Advanced	Beginning		
PRODUCTS				
- Panels	USA, Japan, Europe,	Canada		
- Manholes	Japan			
- Insulators (electric)			USA	USA
- Traffic safety barriers	Canada			
- Tunnels			Japan	
- Machine tool bases		Europe		
- Gutters	Europe, Canada	USA		
- Pipes	Japan		USA	
- Highway repair		Europe	USA, Canada	
- Geothermal applications			USA	USA
- Synthetic marble	USA, Europe, Canada			
PRODUCTION TECHNIQUES				
- Centrifugal casting	Japan			
- Mass casting	Europe, Japan	USA		
- Blowgun casting (gunite type)				USA
- Batch casting		Canada, USA		

landing strip repair), nuclear energy and highways sectors (bridges and expressways) and geothermal sector.

In Europe and the United States, suppliers of raw materials and equipment, on their own initiative or in consultation with their clients, develop uses requiring their products. In most cases, this type of work is carried out in the R&D laboratories of multinational concerns. Canadian subsidiaries of these suppliers of resin know little if anything about polymer concrete and perform hardly any R&D in Canada.

A large number of universities in Europe and the United States contribute to the development of new applications through their fundamental research. Japan is a good example of effective co-operation between the universities and private enterprise in the development of commercial applications using polymer concrete.

In the development of new applications or those based on the requirements of potential users, specific properties must be identified or even modified. In these cases users are the inspirers of pure research projects. Table 30 gives an overview of the R&D situation with respect to polymer concrete in the main industrialized nations.

Formulation of standards for use

The establishment of standards for the use of polymer concrete has been made possible largely through the work done on the identification of properties. The behaviour of polymer concrete types is fairly well known in terms of short-term properties in various conditions of exposure and temperature. The long-term behaviour of polymer concrete is not known, however, except for certain formulations and for limited cases of exposure and mechanical stress. This explains in part why resin concrete products have not been used much for

TABLE 30: Examples of research on resin concrete

COUNTRY	MANUFACTURERS (Private enterprises)	PUBLIC ENTERPRISES	UNIVERSITIES	GOVERNMENTS	
				Contract	Lab.
Japan	X	X	X		
USSR	X				X
Europe	X	X	X		
USA	X		X	X	X
Canada	X				

FIELDS OF R&D	JAPAN	USSR	EUROPE	USA	CANADA
Material					
. Reduction in shrinkage during casting	X	X	X	X	
. Low temperature casting				X	
. Use of wet aggregates				X	
. Reinforcement	X	X	X	X	
. Formulations for specific applications	X	X	X	X	X
Identification of properties					
(Adhesion, creep, etc.)	X	X	X		
Manufacturing techniques	X	X	X	X	
Typical uses:					
. Structural	X	X			
. Electrical				X	
. Highway			X	X	X
. Corrosion resistance	X	X	X	X	
. Nuclear energy				X	
. Hydraulic engineering	X	X	X	X	

structural applications up to now, except in the USSR and Japan, who have done sufficient work on concrete types using their own formulations to be able to use resin concrete for these purposes.

Progress of polymer concrete research

Polymer concrete research is progressing more rapidly in industrialized countries that invest in research and development than it is elsewhere. During the last two international congresses on polymer concrete, in Texas in 1978 and in Koriyama, Japan in 1981, quite a number of countries less industrialized than Canada presented reports on their research or completed projects using polymer concrete (see Table 31). The few reports given at these conferences by the Canadians largely concerned the use of sulphur to replace cement. We can see from the papers presented that the level of technology has been increasing continually since 1975. In addition, the number of interested groups and organizations is rising all the time and applications have multiplied and become more diversified.

In countries where the use of polymer concrete is most widespread, notably in the USSR and Japan, explanatory material on the use of the products has been published; this is read by engineers, architects and designers. In many cases, the need to inform the users takes precedence over research. In Canada, it seems that R&D will be possible only insofar as it can meet the needs of potential users who will be sufficiently informed to know the possible applications of polymer concrete and who will have identified the concrete needs that this material can fulfil. Canadian expertise in pure research is currently very limited, however, and it probably ought to be given a boost.

12.2 Review of Canadian R&D on polymer concrete

Canada has very few pure or applied research projets on the use of polymers with concrete (PIC and PPCC) or as its substitute (PC). Canadian published work on these subjects is more or less limited to a few publications on PIC and work on sulphur concrete.

TABLE 31: Participants in the three international congresses on the use of polymers with cement (PC, PIC and PPCC)

REPORTS PRESENTED	1st LONDON ENGLAND 1975	2nd AUSTIN, TX USA 1978	3rd KORIYAMA JAPAN 1982
NUMBER	54	38	101
TYPE OF ORGANIZATION			
. Universities	16	12	50
. Governments or Industrial Associations	22	16	23
. Private Enterprises	16	8	15
. Public Enterprises	-	1	13
COUNTRY			
Federal Republic of Germany	6	3	5
United Kingdom	12	1	3
Italy	1	1	2
France	1		1
Sweden			3
Norway	1		
Denmark	1		
Netherlands	1		
Belgium	1		
Switzerland	1		
Austria	2		
Spain	1		
USSR		3	11
Poland	1	1	8
Bulgaria	1		1
Romania	1		
Czechoslovakia		1	
Canada	2	1	2
USA	8	22	13
Japan	9	4	35
India	1	1	5
China			7
Thailand	1		2
Egypt			3
Australia	1		
South Africa	1		

It has therefore been found expedient to place R&D opportunities, as formulated by the manufacturers and users of resin concrete products, in the broader context of all Canadian R&D activities, especially in the concrete and plastic sectors.

12.2.1 R&D activities in Canada

In 1981, Canadian R&D work was performed chiefly by private enterprises, the federal government and the universities representing 50%, 24% and 22% respectively of total R&D expenditure in that year. Thirty-five point six percent of these activities were financed by the federal government and 42% by private industry. These data indicate the important role played by the Government of Canada in financing R&D activities, the 1981 total expenditure for which is estimated at 3,5 billion dollars.

Between 1975 and 1978, Canadian R&D expenditure as a proportion of the gross national product (GNP) remained virtually constant at 1%. During the same period, however, most of the industrialized countries allocated much larger percentages to R&D (see Table 32).

Although Canada exports many raw materials, as many of the developing countries do, it also exports its know-how in the form of finished products and management and operational skills for engineering projects in certain less industrialized countries. Not only to meet its own needs but also to remain competitive with other industrialized countries, Canada owes it to itself to invest in R&D.

A recent study prepared by the federal government concluded that Canada probably depends more than most industrialized countries on techniques developed abroad. Imported know-how cannot, however, completely replace domestic R&D and we run the risk of accentuating the problem of Canadian technological dependence on a number of other industrialized countries. Moreover imported technology does not as a rule make Canadian industry internationally competitive. (55)

TABLE 32: R&D in the major industrialized countries

COUNTRY	DRDE as a proportion of GNP* (1977 or 1979) %	Average annual variations in DRDE* during the 70s %
France	1.81	3.1
Federal Republic of Germany	2.27	4.1
Japan	2.04	6.9
United Kingdom	2.20	1.9
USA	2.39	1.5
Australia	0.99	0.8
Belgium	1.37	4.6
Canada	1.04	1.6
Italy	0.89	3.2
Netherlands	1.99	2.7
Sweden	1.87	6.5
Switzerland	2.29	0.8
Denmark	0.99	3.0
Finland	1.02	7.9
Ireland	0.80	5.8
New Zealand	0.82	3.7
Norway	1.40	7.8
Yugoslavia	1.16	6.9

* DRDE: Domestic R & D Expenditure
GNP: Gross National Product

Source: Annual Review of Science Statistics, Statistics Canada, Catalogue 13-212, 1981.

12.2.2 Canadian R&D activities in the field of concrete

Table 33 indicates the extent of Canadian R&D in the field of cement, aggregates and concrete.

TABLE 33: Canadian R&D activities in the field of concrete

YEAR	R & D in the cement sector -A- (In millions of dollars)	Value of cement produced -B- (In millions of dollars)	Gross National Product -C- (In billions of dollars)	"A" as a % of "B"	"A" as a % of "C"
1968	.6	152	72	.4	0008
1973	1.5	242	120	.6	0016
1980*	4.5	650	300	.7	0015

* Estimated value

Funding for research in the cement industry in 1980 came from the following sources:

Federal agencies	19%
Universities	17%
Provincial agencies	27%
Industries	37%

In 1980, the sums invested in R&D projects in the cement industry as a proportion of the value of sales in this industry were twice as low in Canada as they were in France or Britain. In addition, the funds allocated for R&D in the cement industry as a proportion of the gross national product were 3 times as low as they were in Britain and 4 times as low as the French percentage. Unfortunately no statistics are available for the United States. (54)

12.2.3 Canadian R&D activities in the field of plastics

A survey published by the Chemicals Branch of the Department of Industry, Trade and Commerce in 1977 estimated average R&D expenditure by the Canadian plastics industry to be 0,7% of its sales (56). According to Statistics Canada, R&D expenditure by Canadian industries in the rubber and plastics sector was about 5 million dollars in 1975 and 9,2 million dollars in 1980. Because the sums spent on R&D in this sector by the universities and federal and provincial agencies are not included in these figures, we have every reason to believe that total R&D investments in this sector are much higher.

12.2.4 R&D initiatives concerning polymer concretes in Canada

As indicated in Figure 59, PIC and PPCC are cement / polymer composites whereas the resin concrete (PC) types are actually fully loaded plastics.

Since the cement industry carries out extensive research on the various kinds of admixtures, superplasticizers, etc., it would seem logical that it also be interested in PPCC and/or PIC, which are in fact examples of concrete upgraded by the incorporation of polymeric binders. Moreover, since the main role of these products is to replace concrete when its properties are insufficient, portland cement concrete experts would do well to acquaint themselves with the alternatives offered by an improved concrete that can hold its own in difficult applications.

Research on polymer concrete is first and foremost the responsibility of experts in the field of plastics (and more specifically reinforced plastics), especially where the formulation of products is concerned, since the fields of resin concrete and plastics are so similar. Moreover, even though the PC sector obtained its technology partly from the cement concrete industry, PC know-how is different from concrete know-how and familiarity with plastic resins is a basic requirement for efficient and economical production.

Nevertheless, the responsibility for finding new uses for these materials rests largely with present and potential users according to their needs. Optimal development of the products remains a multidisciplinary affair involving engineers, manufacturers, designers and users alike.

12.3 Polymer concrete research needs expressed by manufacturers and users

R&D needs as formulated by producers and users were presented in detail in Section 10 to which the reader is referred. The following is a convenient summary, arranged by category of respondent.

Synthetic marble manufacturers

The R&D priorities established by the poll and presented in 10.1 are:

1. Cost reduction
    a. Reduction in quantity of resin
    b. Automated production equipment
2. Upgrading of products
    a. More resistant gel coats
    b. Increased thermal shock resistance
    c. Reduction in weight

Since the gel coat is the part of a synthetic marble product that is most subject to stress, improving the product's performance must start with improvement of the gel coat's performance. This requires expertise in terms of formulation and compatibility between the gel coat and the base resin.

Labour and resin costs can be lowered through the use of continuous mixers for the fabrication of synthetic marble products. Most Canadian producers do not use such mixers, however, since they usually cannot afford them.

In the short term, changes in resin formulations could reduce costs and the quantity of resin used and improve mechanical properties. The technique using the molecular properties of polymers (IPN - Interpenetrating Polymer Networks - and SIN - Simultaneous Interpenetrating Polymer Networks) creates effects of synergy and could be used to advantage for the synthetic marble industry (57).

The synthetic marble industry contains many small companies most of whose work is manual and who cannot afford to invest in R&D projects. The major ones nevertheless realize the need for such projects and are trying to improve the quality and performance of their products. Two paragraphs from Comment E of Table 24 sum up the needs of this sector rather well:

> "Little research has been done on the subject in the past 15 years. To be competitive, synthetic marble products must offer quality matching their price and possess longterm properties more comparable with those of porcelain.
>
> Increasing the competitiveness of synthetic marble implies an increase in the volume of production resulting from a better appreciation of synthetic marble by the public, provided its weaknesses are corrected."

Polymer concrete manufacturers

The needs expressed by this group of respondents concern the manufacture and performance of polymer concrete products:

Production:

- Develop economical methods of reinforcing polymer concrete
- Deal with the problem of shrinkage during casting
- Develop resin formulations for specific industrial applications
- Develop new products

Performance:

- Determine properties according to the various formulations (in various industrial environments and for prolonged periods)
- Measure resin degradation and fading of colours by the sun.

Since polymer concrete uses polymers as binders, its behaviour will be strongly influenced by temperature. This fact and the rate of creep at average temperatures (60°C) are the main reasons why structural applications for the material are limited.

Knowledge of the long-term behaviour of various formulations submitted to aggressive environments and/or average temperatures would greatly help local manufacturers to penetrate the industrial market. Such knowledge is equally important to potential users since they would be taking a risk by specifying a material with which they were not completely familiar.

The type and method of reinforcement for polymer concrete products must also be given special attention when new products are developed since shrinkage during casting creates stress on the reinforcing and this can cause cracks in the material. Optimalization of formulations to reduce shrinkage is therefore directly linked to the development of economical and effective methods of reinforcing polymer concrete.

Consulting engineers

In general, the Canadian consulting engineers that were consulted had had little experience with polymer concrete products. Even those who had used them indicated the need to be better informed. Their perception of R&D needs therefore relates chiefly to a better knowledge of the properties, performance and behaviour of polymer concrete in various repair and protection applications. Such knowledge was considered a must if these new products were to be used sensibly and if costly errors were to be avoided.

Users

The users polled were in the main satisfied with the behaviour of polymer concrete. Their remarks concerning R&D activities were of two kinds:

- Lack of knowledge about the actual behaviour of the material and the absence of guiding standards for use does not help certain users who consider they are taking a risk.

- For certain applications, impact resistance should be improved by using effective means of reinforcement.

Although it may seem strange at first glance that a great deal of research sould be aimed at determining the properties of polymer concrete, polymer-impregnated concrete and PPCC, the values given in the technical literature can serve only as a guide in evaluating the properties of a particular type of polymer concrete produced for a given application. In the case of a polyester polymer resin concrete, for instance, the properties vary according to the type of resin used, its degree of unsaturation, the ingredients in the formulation (aggregates, cross-linking agents, comonomers, etc.) and conditions of use (see Figure 2). Canadian users need to know the particular properties of polymer concrete types that have been commercialized in Canada so that they may use these products effectively. In addition users want to know how these products behave during long periods of exposure.

Expertise relating to these materials is limited to a small group fo users, and little is known about how to use or choose the materials effectively. In some cases, this leads to badly designed or badly executed work and problems with the behaviour of the material which gives the material a bad name when it is really the improper use of it that is at fault.

Users requiring tests to be conducted on these materials to check their performance in special conditions ought to be able to count on a few "centres of excellence" specialized in PC, PIC and PPCC so that they may be appropriately advised on the use of these products or on the development of new applications.

Furthermore, economic studies comparing the cost and life-long performance of various materials with the same application would encourage the use of these new materials.

12.4 R&D needs: conclusion

Use of polymer concrete

Although polymeric binders are many times more expensive than cement binders, it is possible to produce polymer concrete to compete with portland cement concrete products in terms of price by using appropriate equipment. Moreover, polymer concrete applications can compete with materials more costly than concrete such as steel, aluminium, natural stone, ceramics, etc.

There is no doubt that polymer concrete materials have a future in Canada. Even though the market for certain products remains difficult to assess, the polymer concrete market is a new market and its expansion will depend on the ability of users to make the most of these new materials, i.e. it will depend on their knowledge. Canada's harsh climate causes rapid degradation of concrete, the rate of degradation depending on the severity of the conditions. Interest in polymer concrete will begin where the properties of cement concrete end.

The countries using polymer concrete favour applications that best suit their needs. Canada's needs are similar to those of many of the other countries, but it also has its own particular needs, which are still to be defined on the basis of the applications chosen by potential users. The obervations of the consulting engineers polled point to repair work as a major field of application.

A number of polymer concrete applications are currently at the stage of commercialization. Canada has several good PC (including synthetic marble) and PPCC products on the market. Polymer concrete applications are not so diversified in Canada, however, because potential users still know very little about polymer concrete.

Although polymer concretes has existed for only twenty years or so, the extensive research that has been conducted throughout the world, both in the industrialized and in the underdeveloped countries, is pushing our knowledge ever farther and helping us to develop new applications.

The development of new Canadian applications will have to take place on the basis of local skills, using local pure research and local practical know-how.

R&D needs expressed

The manufacturers of resin concrete products intimated some of their needs and proposed R&D subjects requiring both pure and applied research. In many cases these manufacturers did not have the technical and/or financial means to conduct the research themselves.

Users also expressed their needs. These relate mainly to information on the short and long-term performance of polymer concrete types in various environments. Available technical literature only partially meets their needs.

To satisfy user expectations fully, however, R&D work would have to be carried out to:

- provide information necessary for the design and use of polymer concrete in various formulations and in particular in formulations used by local manufacturers;
- develop in Canada applications that occur elsewhere and would be useful in this country;
- develop new uses adapted to the Canadian situation and fulfilling the needs expressed by actual and potential users.

Canadian R&D

The level of Canadian R&D on polymer concrete is lower than that found in many industrialized countries and even in certain developing countries. Canadian expertise in this field is clearly underdeveloped compared with Canadian polymer concrete consumer potential.

Pure and applied polymer concrete research is actually increasing in many developed countries on several levels. Despite the fact that Canada's needs are comparable to those of other countries, the level of Canadian knowledge of and research on polymer concrete is currently very low. If Canada is to derive full benefit from these materials it will have to develop them on a much larger scale.

The lack of knowledge concerning polymer concrete on the part of potential users, as demonstrated clearly in Section 10, is impeding the expansion of the present market and the development of new products or uses. Indeed, it is the users that are at the bottom of the R&D needs. Expansion of the market is necessary to allow existing enterprises to have more mass production, greater automation and more competitive prices.

The first step in this direction would be to distribute written information on the potential uses of these materials. This information should also assist potential users (engineers, architects, etc.) in the formulation of specifications for polymer concrete according to various applications.

BIBLIOGRAPHY

(1) C. Michaud, INIEX, Belgique, "Les bétons de résines, applications dans le domaine de la construction"; Symposium: Évolution récente de matériaux de construction, Avril 1981, 28-29, Liège, Belgique.

(2) W. Klöker, H. Niesel, "Polyesterbeton und kunststein" (Béton de résine polyester: propriétés, mise en oeuvre, applications), Betonwerk no. 7, 1974, p. 490-496; no. 4, 1975, p. 157-160; no. 5, 1975, p. 252-255.

(3) Reiner Kreis, "Possibilités d'application du béton de résine synthétique", Export market, Vogel-Verlag, no. M-10/1972.

(4) Klaus Marahn, "Éléments en béton de résine synthétique utilisés pour des travaux publics", Export market, Vogel-Verlag, Würzburg, Octobre 1973, Édition no. M-41, .

(5) J. Bricteux, C. Michaux, "Amélioration des caractéristiques des bétons de résine par incorporation de fibres de verre", Plastiques renforcés/fibres de verre/textile, Juin 1980, no. 5.

(6) Richard C. Prusinski, "Study of commercial development in precast polymer concrete", Polymers in concrete, American Concrete Institute, Publication SP-58, 1978.

(7) Anonyme, "Polymer concrete gaining acceptance in Europe", Modern concrete, Octobre 1980, p. 54-55.

(8) P. Koblischek, "Synthetic resin-bound concrete", First International Congress on polymer concretes, London, England, 1975, May 5-8, Session 6, paper 11, 10 pages.

(9) Ralph Ironman, "New market opportunities for polymer concrete", Concrete Products, Février 1982, p. 44-48.

(10) Reiner Kreis, "Machines et unités de fabrication de mise en place et de traitement du béton de résine synthétique", Export Market, Vogel-Verlag Würzburg, Octobre 1974, No. M-49.

(11) Ralph Ironman, "Weegels of Weert", Concrete Products, Septembre 1979.

(12) Ralph Ironman, "A progress report on resin concrete", Concrete Products, Août 1977.

(13) Richard C. Prusinski, "Precast polymer concrete: a twenty year history", SPE, East New England Sect. Plastics in building, Retec, Boston, Mass. Novembre 1976, p. 1-21.

(14) D.W. Fowler, A.H. Meyer, D.R. Paul, "Low temperature curing of polymer concrete", Polymers in concrete, Third International Congress, Koriyama, Japan, 1981, May 13-15, p. 421-434.

(15) Anonyme, "Une nouvelle technologie pour la construction de machines", L'Officiel des plastiques et du caoutchouc, Juillet/Août 1980, p. 351-359.

(16) K. Okada et Y. Ohama, "Status of concrete-polymer composites in Japan", Polymers in concrete, Third International Congress, Koriyama, Japan, 1981, May 13-15, p. 3-19.

(17) Y. Ohama, "Development of concrete polymer materials in Japan", Polymers in concrete, Second International Congress, University of Texas, 1978, Octobre 25-27, p. 121-137.

(18) Koji Imamura, NTT Japan, "Precast polymer concrete for utility applications", Polymers in concrete, Second International Congress, University of Texas, Austin, U.S.A., 1978, October, 25-27, p. 173-186.

(19) T. Matsuura, T. Konaka, "Quick setting resin mortar", Polymers in concrete, Third International Congress, Koriyama, Japan, 1981, May 13-15, p. 584-613.

(20) D.W. Fowler, D.R. Paul, "Status of concrete-polymer materials in the United States", Polymers in concrete, Third International Congress, Koriyama, Japan, 1981, May 13-15, p. 20-34.

(21) R. Martino, "New Markets for molders in polymer concrete", Modern Plastics, Mai 1980, p. 46-49.

(22) J.T. Dikeou, "Development and use of polymer concrete and polymer impregnated concrete", Progress in concrete technology, Canmet, Ottawa, 1980, Édité par V.M. Malhotra, p. 539-582.

(23) T. Sugama, "Water compatible polymer concrete materials for use in rapid repairs", Brookheaven National Laboratory, New York, U.S.A. Mars 1981, 114 pages.

(24) J.E. Schroeder, Lindsey Industries, Azusa, Ca. 91702, U.S.A., "Design and fabrication of polymer concrete, pipe for testing in geothermal energy processes", pour le Brookhaven National Laboratory, contract no. 436337-S, Juillet 1981.

(25) C. Steele, "Polymer concrete precaster import mass production method", Modern concrete, Mai 1981, p. 38-42.

(26) J.E. Schroeder, "An evaluation of polysil as an insulating material", IEEE Transactions on Electrical insulations, Vol. EI-16, Octobre 1981, no. 5, p. 446-452.

(27) E. Robert Perry, "Polymer concrete and the electric power industry", Applications of polymer concrete, American concrete institute, publication S-69, 1981.

(28) M. Gunasekaran, "Development of poymer concrete electric substation structure", Polymer in concrete, Third International Congress, Koriyama, Japan, 1981, May 13-15, p. 731-743.

(29) M. Steinberg, J.T. Kikeou, "Concrete polymer materials, First topical report", Brookhaven National Laboratory, Décembre 1968, BNL no. 50134 (T-509).

(30) Anonyme, "Polymers in concrete", ACI committee 548, American concrete Institute, Detroit, Michigan, U.S.A., 1977, 92 pages.

(31) J.A. Manson, "Overview of current research on polymer concrete: materials and future needs", Applications of polymer concrete, American concrete Institute, Detroit, U.S.A. 1981, Publication SP-69, p. 1-20.

(32) Bartholomew J., Fowler D.W., Paul D.R., "Current status of bridge deck impregnation", Polymers in concrete, Second International Congress, University of Texas, Austin, U.S.A., 1978, October, 25-27, p. 395-412.

(33) M. Ebara, T. Kawanami, "Process technology for production of PIC pipes by use of closed forms", Polymers in concrete, Third International Congress, Koriyama, Japan, 1981, May 13-15, p. 967-973.

(34) Zhuang Ju, "Partial drying impregnation technology in manufacture of 15 atm PIC gas supply pipes", Polymers in concrete, Third International Congress, Koriyama, Japan, 1981, May 13-15, p. 974-986.

(35) T. Yamamota, Y. Ohama, "Basic study of process technology of polymer impregnated gypsum", Polymers in concrete, Third International Congress, Koriyama, Japan, 1981, May 13-15, p. 1131-1140.

(36) S. Seki et K. Ueda, "Strenght of polymer impregnated gypsum-slag hardened mixture", Polymers in concrete, Third International Congress, Koriyama, Japan, 1981, May 13-15, p. 1123-1130.

(37) A. Donato, "Studies on polymer impregnated cement for radioactive waste conditioning in Italy", Polymer in concrete, Second International Congress, University of Texas, Austin, U.S.A., 1978, October 25-27, p. 193-210.

(38) V.R. Riley et I. Razl, "Polymer additives for cement composites: a review", Composites, Janvier 1974, p. 27-33.

(39) Y. Ohama, "Adhesion durability of polymer-modified mortars through ten years outdoor exposure", Polymers in concrete, Third International Congress, Koriyama, Japan, 1981, May 13-15, p. 209-222.

(40) Y. Ohama, S. Suzuki, "Incombustibility of polymer modified mortars", Polymers in concrete, Third international congress, Koriyama, Japan, 1981, May 13-15, p. 222-233.

(41) Y. Kasai, I. Matsui, Y. Fukushima, "Physical properties of polymer-modified mortars", Polymers in concrete, Third International Congress, Koriyama, Japan, 1981, May 13-15, p. 178-192.

(42) David W. Fowler, Chairman, committee 548 ACI, "Applications of polymer concrete", American Concrete Institute, Détroit, U.S.A., Publication SP-69, 222 pages.

(43) J. Alexanderson, "Polymer cement concrete for industrial floors", Polymers in concrete, Third International Congress, Koriyama, Japan, 1981, May 13-15, p. 360-373.

(44) L.A. Kuhlman, "Performance history of latex-modified concrete overlay", Application of polymer concrete, American Concrete Institute, Detroit, U.S.A., 1981, Publication SP-69, p. 123-144.

(45) J.T. Dikeou, E.K. Schrader, "Polymer modified glass fiber reinforced mortar coastings portect navigation lock-walls", Polymers in concrete, Third international congress, Koriyama, Japan, May 13-15, p. 331-346.

(46) Yves R. La Palme, Canfarge Ltée, Montréal, "Gel-coat sur béton de ciment", Institut de génie des matériaux, étude no. 15, CNRC no. 18987.

(47) Morris Schupack, "Divorces and ruptured relations between expoxies and concrete; some clues are offered to cases of incompatibility", Concrete construction, Octobre 1980, p. 735-738.

(48) R.A. Bares, "Causes of polyester resin-filler surfacing systems failure", Polymers in concrete, Second international congress, University of Texas, Austin USA, 1978, October 25-27, p. 311-330.

(49) David B. Richardson, "To rebuild America -2,5 trillion $ job", U.S. News and world report, 27 septembre 1982, p. 57-61.

(50) Malcom Baldrige Sec., U.S. Dept. of Commerce, "1982 U.S. Industrial outlook for 200 industries with projections for 1986", U.S. Government Printing Office, chap. 1: construction p. 1-10, chap. 2: builging materials, p. 11-23.

(51) Daniel P. Poisson, "Étude de rentabilité sur l'utilisation du granite de construction pour les travaux publics", CRIQ, Février 1979, no. 5-0757 (1953).

(52) V.V. Paturoev, A.M. Fantalov, "Fundamentals of P-concrete structure formation and factory technology", Polymers in concrete, Third International Congress, Koriyama, Japan, 1981, May 13-15, p. 637-651.

(53) Anonyme, "Plastics help concrete bear the load", Modern Plastics, Janvier 1974, p. 53-54.

(54) Adam M. Neville, Canmet, "Aggregate, cement and concrete research in Canada, 1980", Energy and Ressources Canada, Septembre 1981, Rep. no. OSQ 81-0074.

(55) Anonyme, "L'importation de la recherche et du développement invisibles", Document explicatif no. 3 du ministère d'État à la Science et à la Technologie, Ottawa, Juillet 1978, 33 pages, p. 8.

(56) Anonyme, "L'industrie canadienne de la transformation des matières plastiques", Direction des produits chimiques, ministère de l'Industrie et du Commerce, Ottawa, 1977, 48 pages.

(57) L.H. Sperling, "Interpenetrating polymer networks: a new class of materials", Materials engineering, Sept. 1980, p. 66-70.

Référence complémentaire

Yoshihiko Ohama, "Bibliography on Polymers in Concrete", Dept. of Architecture, College of Engineering, Nihon University Kuroyama, Fukushima, Japan", mai 1981, 374 pages (contient 2278 références de documents en anglais, allemand, français, suédois, polonais et japonais).

APPENDIX 1

SURVEY CONDUCTED AMONG MANUFACTURERS OF SYNTHETIC MARBLE PRODUCTS

QUESTIONNAIRE AND LIST OF BUSINESSES CONTACTED

LES BETONS POLYMERES

EVALUATION TECHNICO-ECONOMIQUE

1- NOM DE LA FIRME: ____________________
ADRESSE DE LA FIRME: ____________________
CODE POSTAL: ____________________
TELEPHONE ____________ TELEX ____________

2- NOM DE LA COMPAGNIE-MERE: ____________________
(si différente de l' ADRESSE): ____________________
____________________ CODE POSTAL ________

3- NOM DU REPONDANT AU QUESTIONNAIRE: ____________________
FONCTION DU REPONDANT: ____________________

4- Activités principales de l'entreprise telles que:
- produits fabriqués
- type de production: automatisée ou manuelle
- type de matériaux utilisés.

____
____
____
____
____
____

5- Taille de l'entreprise:
Nombre d'employés: __________

6- Si vous fabriquez des produits en béton polymère du type "marbre synthétique",

a) Fabriquez-vous vos propres moules? oui ☐ non ☐

b) Seriez-vous intéressé par des formulations permettant de réduire d'environ 50% la quantité de résine utilisée actuellement? oui ☐ non ☐

c) Une augmentation du poids de 10 à 15% serait-elle un empêchement majeur?
oui ☐ non ☐

7- Votre savoir-faire dans la fabrication des produits en béton polymère vient-il principalement:

☐ de recherches effectuées par votre entreprise

☐ d'accords de fabrication sous licence ou d'ententes contractuelles avec d'autres compagnies

☐ de l'information obtenue des fournisseurs (matières premières, équipements)

☐ de recherches effectuées par votre compagnie mère

☐ autres, S.V.P. spécifiez:

____

____

8- Selon vous, à quels problèmes principaux devrait s'attaquer la recherche et développement dans le domaine du marbre synthétique pour réduire vos coûts de fabrication ou améliorer vos produits ?

a) Améliorations des performances des produits finis telles que:

☐ résistance aux chocs thermiques

☐ réduction du poids

☐ emploi de matières premières moins coûteuses

☐ autres: ______________________________

____

____

b) Pour compétitionner plus efficacement les autres matériaux, quelles possibilités de réduction des coûts devraient être explorées (méthodes de production, équipements à développer, résines, "fillers", ...

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9- En plus des produits en "marbre synthétique", fabriquez-vous (ou avez-vous déjà fabriqué) des produits en béton polymère d'un autre type?

oui ☐ non ☐

Si oui, précisez le type et les produits fabriqués:

____

____

____

____

10- Comment percevez-vous l'avenir des bétons polymères au Canada? (Ex.: marché actuel et prévisible, secteurs prometteurs, nouveaux produits, besoins en R&D, quelles contraintes freinent actuellement le développement de ces matériaux?)

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Nous vous remercions d'avoir complété ce questionnaire. Si vous désirez obtenir copie du sommaire de cette étude, nous vous saurions gré de bien vouloir nous l'indiquer ici.

oui ☐ non ☐

Nom: ____________________

Date: ____________________

TECHNO-ECONOMICAL SURVEY

1. COMPANY IDENTIFICATION

Name: ______________________________

Address: ______________________________

____

Postal Code: ______________________________

Telephone: ______________ Telex or TWX: ______

2. PARENT COMPANY IDENTIFICATION (if different of #1)

Name: ______________________________

Address: ______________________________

____

Telephone: ______________ Telex or TWX: ______

3. ANSWERER IDENTIFICATION

Name: ______________________________

Title: ______________________________

4. MAIN COMPANY ACTIVITIES

- Products made: ______________________________

  ____

- Type of production: automatic or manual: ________

  ____

- Raw materials used: ______________________________

  ____

5. COMPANY SIZE:

Number of employees: ________

6. If you make polymer-concrete products of synthetic marble type

A) do you make your own molds: yes ☐ no ☐

B) would you be interested by formulations allowing a reduction of almost 50% in the resin quantity used?
yes ☐ no ☐

C) would an increase of 10-15% in weight of the final product be a major drawback?
☐ yes ☐ no

CENTRE DE RECHERCHE INDUSTRIELLE DU QUÉBEC, 333, rue Franquet, C.P. 9038, Sainte-Foy (Québec), CANADA G1V 4C7
(418) 659-1550, Télex 051-31569.

7. Your knowledge of polymer concrete (PC) technology comes from:

☐ internal R&D projects
☐ licence or contract agreement with other companies
☐ data obtained from equipment or raw materials supplier
☐ parent-company R&D
☐ other sources (please specify): ____________________
____
____

8. From your point of view, what should be the most important research and development fields, the synthetic marble industry should look at, in order to reduce fabrication costs or improve products:

A) finished product characteristics improvement, such as:
  ☐ thermal shock resistance
  ☐ weight reduction
  ☐ the use of cheaper raw materials
  ☐ other characteristic, please specify: ____________
____
____

B) in order to get finished products more competitive, what cost reduction options should be examined (processes to develop, equipment to design, resins, fillers, etc...)
____
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9. In addition to "synthetic marble", do you (or did you) use other types of polymer concretes in your production?

☐ yes, please specify the type used and the products made thereof: ____________________

____

____

☐ no

10. From your point of view, is there a future for PC in Canada? Please explain: actual and foreseeable market, promising applications/sectors, new products, R&D needs, actual and future limitations?

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We thank you for having filled this questionnaire. If you would like to get a summary of this study, please check:

☐ yes, I'm interested

☐ no

____________________ signature ____________ date

Liste des manufacturiers canadiens de marbre synthétique

AARO MARBRE
7810H Jarry East
VILLE D'ANJOU, Québec
H1J 2A1

ACME MARBLE
670, Harwick Road
BOLTON, Ontario
L0P 1A0

ADVANCE CULTURED MARBLE LTD
175, Advance Blvd
TORONTO, Ontario
M2R 3G4

AJAX MARBLE
220, Clements Road, Unit 8
AJAX, Ontario
L1S 3K5

ARTISTCRAFT MARBLE
369, Bering Avenue
ETOBICOKE, Ontario

CALEDONIA MARBLE CO.
176, Betworth Avenue
TORONTO, Ontario
M2R 3G4

CANADIAN CULTURED MARBLE LTD
1971 McLean Avenue
PORT COQUITLAM, B.C.
V2P 1A1

CANADIAN VANITIES
P.O. Box 233
WINGHAM, Ontario
N0G 2W0

CAST MARBLE MFG. LTD
1251 No. 2 Road
RICHMOND, B.C.
V7E 2G3

COLOURTONE CULTURED MARBLE
442 Brimley Road, Unit 6
SCARBOROUGH, Ontario
M1K 5C3

CONCORD MARBLE & FIBERGLASS
96 Bowes Road
CONCORD, Ontario
L4K 1B1

CONI MARBLE
Harrison Street
THORNDALE, Ontario
N0M 2P0

CORNERSTONE MARBLE ENTERPRISE
6-2001 Thickson S.
WHITBY OSHAWA, Ontario
L1N 6J3

CULTURED MARBLE CO.
51 Esna Park Drive
MARKHAM, Ontario
L3R 1C9

CUNDAL MARBLE LIMITED
1372 Hastings Cres. S.E.
CALGARY, Alberta
T2G 4C9

DECOMARBRE INC.
2144 de la Métropole
LONGUEUIL, Québec
J4G 1R5

DYNEL MARBLE INDUSTRIES LTD
1035 Alston Street
VICTORIA, B.C.
V8L 1A1

ELEVEN SEVENTEEN SALES
26 Doncaster
OTTAWA, Ontario
K1V 8R7

GRANOMO & DURO STONE LTD
8700 Crescent
ANJOU, Québec
H1J 1A2

H & M MARBLE
German School Rd. R.R. 1
PARIS, Ontario
N3L 3E4

H.R. CHALLENGER
1-63 Spruce Street
OTTAWA, Ontario
K1R 6N8

HOUSE OF MARBLE
113 Mutual Street
INGERSOLL, Ontario
N5C 1Z8

I.E. M.C.S.
P.O. Box 363
PORT HOPE, Ontario
L1A 3Z3

INDUSTRIES FLEURCO (1963) LTÉE
5635 Fullum
MONTRÉAL, Québec
H2G 2H6

ISLAND MARBLE PRODUCTS LTD
6829 Veyaness St., R.R. 2
SAANICHTON, B.C.
V0S 1M0

JIM WALTER BUILDING PROD. LTD
31 Patterson Road
BARRIE, Ontario
L4N 3V9

K.C. DON LTD
400 des Meurons
ST. BONIFACE, Manitoba
R9A 1K2

K-MARBLE MFG. CO. LTD
2330 Tyner St., Unit 12
PORT COQUITLAM, B.C.
V3C 2Z1

KASCOTE MARBLE LTD
280 9th Street West
CORNWALL, Ontario
K6J 3A6

LOMBARDI INDUSTRIES
240 Newburg Rd.
NAPANEE, Ontario
K7R 1C9

LORENZO INDUSTRIES INC.
5750, côte St-François
MONTRÉAL, Québec
H2P 2V1

LUXURY MARBLE LTD
216 E. Esplanade, 1
NORTH VANCOUVER, B.C.
V7L 1A3

LYNN-PRO MARBRE
62 Pépin Street
ST-EUSTACHE, Québec
J7R 5B6

LYN PRO MARBLE CO. LTD
330, des Prairies
LAVAL DES RAPIDES, Québec
H2P 2V1

M & M PRODUCTS
456 Arvin Avenue
STONEY CREEK, Ontario
L8H 6P5

MAIN MARBLE CRAFT MFG. LTD
1217 Bridgeport Rd., 12
RICHMOND, B.C.
V6V 1J4

MALBRO INC.
10019 Mirabeau Street
VILLE D'ANJOU, Québec
H1J 1T7

MARBELEX (1981) ENR.
8940, Champ d'Eau
MONTRÉAL, Québec
H1P 2Y8

MARBLE ART CO.
18 Ingram Dr.
TORONTO, Ontario
M6M 2L6

MARBLELAST MANUFACTURING LTD
4-939 Dillingham
SOUTH PICKERING, Ontario
L1W 1Z7

MARBLEX IND. SUMMERSTOWN
CORNWALL, Ontario
K6H 5R8

MARBRE CULTIVÉ DU QUÉBEC
SAINT-MICHEL (Bellechasse)
Québec
G0R 3S0

MARBRES BERCO LTÉE
609, Iberville
SAINT-PAUL L'ERMITE
Québec
H2P 2V1

MARITIME TILE CO. LTD
3715, Joseph Howe Dr.
HALIFAX, N.S.
B3L 4H8

MARMAC MANUFACTURING LTD
4636, Manilla Rd. S.E.
CALGARY, Alberta
T2G 4B7

MARMAC MANUFACTURING LTD
8645 63rd Avenue
EDMONTON, Alberta
T6E 0E8

MARTONE PRODUCTS LTD
12903 146th Street
EDMONTON, Alberta
T5L 2H6

MARVEL PRODUCTS LIMITED
4227 25A Avenue
VERNON, B.C.
V1T 7G8

MARBLIZED PRODUCTS OF B.C.
DELTA, B.C.
V4E 2A7

McDONALD GRANITE CO. (1965) LTD
CALGARY, Alberta
T2G 2L2

MIAMI CAREY CO.
279, Rexdale Blvd.
REXDALE, Ontario
M9W 1R1

MONARCH MARBLE PRODUCTS LTD
751 Farewell
OSHAWA, Ontario
L1H 6N4

NEWLIN PLASTICS LTD
EDMONTON, Alberta
T6B 0A5

NEW WORLD MARBLE PRODUCTS LTD
Hammond Plains Rd.
BEDFORD, N.S.
B0N 1B0

NIKOLAI PLASTICS LTD
BURNABY, B.C.
V8A 4Z4

NUROLIN INDUSTRIES LTD
210, Telson
UNIONVILLE, Ontario
N0L 2L0

OKANAGAN MARBLE LIMITED
880, Leathead Road
KELOWNA, B.C.
V1X 2J8

QUÉBEC MARBRE
406A, Jean Talon Ouest
MONTRÉAL, Québec
H4P 1W6

REMCO MEMORIALS
611 6th Avenue E
REGINA, Saskatchewan
S4N 5A3

ROGINE PRODUCTS
27 Lynnbrook
SCARBOROUGH, Ontario

ROMAN MARBLE PRODUCTS LTD
2325, ave North
SASKATOON, Saskatchewan
S7N 0W0

RUFEL MARBLE PRODUCTS
P.O. Box 606
SAULT SAINTE-MARIE,
Ontario
P5A 5N2

SCRIPTAM INDUSTRIES WESTERN LTD
1041-1049, Erin Street
WINNIPEG, Manitoba
R3G 2X1

SIMCOE MARBLE
2399, Cawthra Rd., Unit 36
MISSISSAUGA, Ontario
L5A 2W9

SM DISTRIBUTION
592, Liège E.
MONTRÉAL, Québec
H2P 1K1

STATE MARBLE LTD
21, Bradwick
THORNHILL, Ontario
L3T 3M9

SUPERIOR MARBLE & FIBERGLASS CO.
P.O. Box 895
PORT PERRY, Ontario
L0B 1N0

TIFFANY CULTURED MARBLE PRODUCTS
65, Bowes, Unit 7
TORONTO, Ontario
M2R 3G4

TIFFANY MARBLE
301, North Front St.
SARNIA, Ontario
N7T 7H7

THE MARBLE FACTORY
45, Trottier Bay
WINNIPEG, Manitoba
R3T 3R3

TRENCH ELECTRIC LIMITED
390, Midwest Road
SCARBOROUGH, Ontario
N4S 7W4

V & R SENSATIONAL MARBLE & FIBERGLASS
PRODUCTS LIMITED
250, Rayette Rd, Unit 4
CONCORD, Ontario
L4K 1B1

VAN-CITY CULTURED MARBLE
1685, Venables Street
VANCOUVER, B.C.
V5L 2H1

VAN MAR
26, Doncaster Road
OTTAWA, Ontario
K1G 0N1

VANCOUVER MARBLE REPRODUCTIONS LTD
1626, Venables Street
VANCOUVER, B.C.
V5L 2H2

VANIER MARBLE LIMITED
2295, Stevenage Dr.
VILLE VANIER, Québec
G1M 1S0

VENETIAN MARBLE CO. ALBERTA
4636, Manilla Rd, W.W.
CALGARY, Alberta
T1A 1A1

VISTA MARBLE CO.
1105, Glenmore Street
KELOWNA, B.C.
V1Y 3E3

WESKAN IND. LIMITED
Debert Industrial Park
DEBERT, Nova Scotia
B0M 1G0

APPENDIX 2

SURVEY CONDUCTED AMONG CONSULTING ENGINEERING FIRMS

QUESTIONNAIRE AND LIST OF FIRMS CONTACTED

LES BETONS POLYMERES
EVALUATION TECHNICO-ECONOMIQUE

1- NOM DE LA FIRME: ______________________________
ADRESSE DE LA FIRME: ______________________________
CODE POSTAL: ______________________________
TELEPHONE: ____________________ TELEX: ______________

2- NOM DU REPONDANT AU QUESTIONNAIRE: ____________________
FONCTION DU REPONDANT: ______________________________

3- VOTRE CONNAISSANCE DE L'UTILISATION DES BETONS POLYMERES (B.P.) VIENT DU FAIT QUE:

☐ Vous avez pris connaissance de données techniques et/ou commerciales publiées sur le sujet.

☐ Vous avez déjà réalisé des travaux de recherche ou une étude sur le sujet.

☐ Vous avez déjà étudié la possibilité d'utiliser ce matériau pour la réalisation de certains projets

☐ Vous avez assisté à des expositions, conférences, symposiums, colloques, présentés sur le sujet.

☐ Autres (précisez) ______________________________
____
____
____
____

4- Votre firme a-t-elle déjà utilisé (ou envisagé d'utiliser) les bétons polymères pour l'un de ses projets?

☐ oui De quel type de béton polymère s'agissait-il:
PIC ☐ PC ☐ PCC ☐ Autre ☐

☐ non

5- Si votre firme a déjà utilisé ce matériau pour ses projets, décrivez les travaux réalisés et vos commentaires: (type de B.P. utilisé, raisons qui ont conduit au choix des B.P., impression sur le coût du matériel, etc...)

Travaux réalisés	Endroit/date	Commentaires

6- Si votre entreprise n'a pas encore utilisé les B.P.,

a) quel type de B.P. avait suscité votre intérêt?

☐ PIC ☐ PC ☐ PCC ☐ Autre

b) pour quelles raisons avez-vous décidé de ne pas utiliser le B.P.?

- ☐ matériaux peu connus ☐ coûts élevés des matériaux
- ☐ non-confiance envers les dits matériaux
- ☐ impossibilité de trouver une utilisation intéressante
- ☐ impossibilité d'identifier un projet pour lequel l'un de ces matériaux soit utilisable
- ☐ produit pas assez disponible commercialement
- ☐ absence de normes spécifiquement reliées à ces matériaux
- ☐ méconnaissance des performances du matériel pour l'application considérée
- ☐ résistance naturelle de l'utilisateur aux changements
- ☐ autres ______________________________

7- Comment percevez-vous l'avenir des bétons polymères au Canada? (Ex.: marché actuel et prévisible, secteurs prometteurs, nouveaux produits, besoins en R-D, quelles contraintes freinent actuellement le développement de ces matériaux?)

____
____
____
____
____
____
____
____
____
____

8- Connaissez-vous des firmes (consultants, architectes, centres de recherche, industries manufacturières) qui ont acquis de l'expérience dans l'utilisation de l'un ou l'autre type de béton polymère? Si oui, lesquelles:

Nom de la firme	Adresse	Nom de la personne à contacter

9- Seriez-vous intéressé par un document synthèse faisant le point sur les réalisations actuelles utilisant les bétons polymères?

☐ oui ☐ non

10- Nous vous remercions d'avoir complété ce questionnaire. Si vous désirez obtenir copie du sommaire de cette étude, nous vous saurions gré de bien vouloir nous l'indiquer ici.

☐ oui ☐ non

Nom: ____________________

Date: ____________________

POLYMER CONCRETE
TECHNO-ECONOMICAL SURVEY

1- COMPANY IDENTIFICATION:

NAME: ______________________________

ADDRESS: ______________________________

____

PROVINCE/STATE, ZIP: ____________________

TELEPHONE: ______________ TELEX, TWX: ________

2- ANSWERER IDENTIFICATION:

NAME: ______________________________

TITLE: ______________________________

3- Your knowledge of polymer concrete (PC) and its uses comes from:

☐ Commercial publications or data sheet

☐ Your own research work or study

☐ You already have the possibility to use this material for one (or more) particular projects

☐ Shows, conferences, symposiums, colloquies, etc...

☐ Other sources (please specify) : ____________

____

____

4- If you have used (or thought of using) PC in one (or more) of your projects, what particular type was considered?

☐ PIC ☐ PC ☐ PCC ☐ Other (plese specify): ____________

5- If you did use PC, please describe projects, realized products and the reasons why this type of material was chosen (price/quality ratio ,...)

Location/Date	Works	Comments

6- If you have never used PC, why so?

☐ Unknown material
☐ Cost
☐ No confidence in the material
☐ No interesting application
☐ No commercial availability
☐ No standards
☐ Unknown performances, for the considered application
☐ Other reason (please specify): ______________________

7- From your point of view, is there a future for PC in Canada? Please explain: actual and foreseeable market, promising applications/sectors, new products, R&D needs, actual and future limitations?

8- Do you have in mind other companies or groups (consultants, research centers, industries, universities, etc.) already involved in PC use? Please list them:

Company/institution name	Location	Person to contact

9- What would be your interest for a synthesis report on actual uses of PC?

☐ I would like to get a copy of it
☐ No interest

10- Would you like to get a summary of the study we are realizing?

☐ I would like to get a copy of it

☐ No interest

We thank you for answering this questionnaire, please sign

name

date

NOUVEAU-BRUNSWICK (NEW BRUNSWICK)

K.O. Bartlett
ADI Limited
1115 Regent Street
P.O. Box 44, Station "A"
Fredericton, New Brunswick
E3B 4Y2

J.B. Robinson
W.H. Crandall & Associates (Mgt.) Ltd.
1077 St. George Blvd.
Moncton, New Brunswick
EIE 4C9

ILE DU PRINCE ÉDOUARD (PRINCE EDWARD ISLAND)

L. A. Coles
Coles Associates Ltd.
197 Malpeque Road, West Royalty
P.O. Box 695
Charlottetown, Prince Edward Island
CIA 7L3

TERRE NEUVE (NEWFOUNDLAND)

E. K. Jerrett
Jerrett & Associates Ltd.
(E.K. Jerrett & Associates Ltd.)
Con Bay Highway
P.O. Box 760
Bay Roberts Newfoundland
AOA IGO

NOUVELLE ÉCOSSE (NOVA SCOTIA)

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CBCL Limited
6100 Young Street
P.O. Box 1269N
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B3K 5H4

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J. Philip Vaughan & Associates Limited
1660 Hollis Street
P.O. Box 2045, Stn "M"
Halifax, Nova Scotia
B3J 2ZI

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Swan Wooster Engineering Service
Company Limited
1820 Hollis Street
P.O. Box 263
Halifax, Nova Scotia
B3J 2N7

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Whitman Benn & Associates Ltd.
Duke Street Tower, Scotia Square
Suite 212
Halifax, Nova Scotia
B3J IN9

J. Beasy
Beasy Nicoll Engineering Limited
6080 Young Street
Suite 512
Halifax, Nova Scotia
B3K 5L2

F.W. Orlando
Shawinigan Engineering Maritimes Limited
11 Morris Drive, Suite 212
P.O. Box 1286
Dartmouth, Nova Scotia
B2Y 4B9

Sydney Design Associates
P.O. Box 1324
Sydney, Nova Scotia
BIP 6K2

V. Zahorski
Fenco Consultants Ltd.
2000 Barrington Street
Suite 1020, Cogswell Towers
Halifax, Nova Scotia
B3J 3KI

J.D. Koppernaes
J.D. Koppernaes Engineering Ltd.
1248 Bedford Highway
Bedford, Nova Scotia
B4A IC6

C.J. MacLellan
C.J. MacLellan & Associates Ltd.
42 West Street
Municipal Building
Antigonish, Nova Scotia
B2G IR8

W.N. Horner
W.N. Horner & Associates Limited
89 Queen Street
Truro, Nova Scotia
B2N 2B2

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Tremblay, Bouchard & Associés
583, rue St-Dominique
Jonquière, Québec
G7X 6M6

J. Lanthier
Tremblay Rinfret Tremblay Lanthier
393 est, rue Racine
Chicoutimi, Québec
G7H IT2

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P.J. Tyler & Associates
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Westmount, Québec
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Vézina, Fortier & Associés
3300, boul. Cavendish
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H4B 2M8

J.-C. Tremblay
Tremblay, Deschênes et Associés
229, Boulevard LaSalle
Baie-Comeau, Québec
G4Z IS7

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Regis Trudeau & Associés Inc.
110 ouest, rue Crémazie
Bureau 1110
Montréal, Québec
H2P IB9

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Hebert L. Wax & Associates
8375 Bougainville Street
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Aime St-Amant
St-Amant, Vézina, Vinet, Brassard
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Les Consultants SBCS Inc.
2702 ouest, rue Galt
Sherbrooke, Québec
JIK 2V8

J.P. Gourdeau
Le Groupe SNC T
The SNC Group/El Grupo SNC
1, Complexe Desjardins
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Société Municor Inc.
147 Chemin Chambly
Bureau 500
Longueuil, Québec
J4J 3X3

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Roche Associés Limitée Groupe Conseil
2535 Boulevard Laurier
Ste-Foy, Québec
GIV 4M3

The Shawinigan Engineering Company Limited
620 Dorchester Blvd. West
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H3B 3L7

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P K Ingénieurs-conseils
P K Consulting Engineers
639 St-Jacques
Granby, Québec
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Leclair, Riel, Dionne & Associés
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Bureau 510
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Lorrain, Maccabes & Associés
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Lemieux, Royer, Donaldson, Fiels, N
Nadeau, Fouquette, Blais, Morin,
Demers, Letendresse & Associés
150 nord, rue Vimy
Sherbrooke, Québec
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Martineau, Vallee, Regimbald Inc.
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Bureau 302,
Ste-Foy, Québec
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Bureau 200
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Hatch & Associés (Québec) Inc.
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Laval, Québec
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D.J.W. Little
Municipal Planning Consultants
Division of MPC Limited
400 Mount Pleasant Road
Suite 2
Toronto, Ontario
M4S 2L6

E.M. Peto
Peto MacCallum Ltd.
165 Cartwright Avenue
Toronto, Ontario
M6A IV5

A.E. Read
Read, Voorhees & Associates Ltd.
160 Duncan Mill Road
Don Mills, Ontario
M3B IZ5

J.L. Richards
J.L. Richards & Associates Limited
864 Lady Ellen Place
Ottawa, Ontario
KIZ 5M2

P. Hertzberg
Proctor & Redfern Limited
75 Eglinton Avenue East
Toronto, Ontario
M4P IH3

D.F. Quan
Quan, Carruthers, King & Quan Consultants
Limited
1245 Martin Grove Road
Rexdale, Ontario
M9W 4X2

R. Southward
Southward Consultants Limited
2289 Fairview Street
Suite 428
Burlington, Ontario
L7R 2E3

J.E. Robson
Steel Technology Limited
1160 Blair Road
Suite 9
Burlington, Ontario
L7M IK9

W. R. Swain
Swain & Rupnow Ltd.
30 Dupont Street East
Waterloo, Ontario
N2J 2G9

L.S. Mitchell
TMP Consulting Engineers
59 Mobile Drive
Toronto, Ontario
M4A IH8

G.L. Totten
Totten, Sims, Hubicki Associates Ltd.
1500 Hopkins Street
Whitby, Ontario
LIN 2C3

R.L. Williamson
Spectrum Engineering Corporation Ltd.
544 McDonnel Street
P.O. Box 687
Peterborough, Ontario
K9J 7A5

A.L. McAnuff
VME Associates Limited
89 Galaxy Boulevard
Suite 19
Rexdale, Ontario
M9W 6A4

C.D. Thompson
The Trow Group Limited
43 Baywood Road
Rexdale, Ontario
M9V 3Y8

J.J. Fedy
Walter, Fedy, McCargar, Hachborn
546 Belmont Avenue West
P.O. Box 368
Kitchener, Ontario
N2G 3Y9

N. D. Pappas
R.E. Winter & Associates Limited
77 City Centre Drive
Mississauga, Ontario
L5B IM5

F.Z. Sobolak
Wyllie & Ufnal Ltd.
I Greensboro Drive
Suite 300
Toronto, Ontario
M9W IC8

H.K. Craibbe
WOBCO Associates Limited
83 Kennedy Road South
Unit I803
Brampton, Ontario
L6W 3GI

P.B. Walters
Paul B. Walters & Associates Ltd.
4166 Dundas Street West
Toronto, Ontario
M8X IX3

C.A. Stevenson
Stevenson, Hluchan Associates Limited
Two Lansing Square
Suite 1106
Willowdale, Ontario
M2J 4P8

V.R.O. Praskey
H. Sutcliffe Limited
9 Wellington Street
P.O. Box 1208
New Liskeard, Ontario
POJ IPO

H.E.H. Roy
SWR Engineering Limited
40 University Avenue
Suite 400
Toronto, Ontario
M5J 2G3

H.H. Todgham
Todgham and Case Associates Incorporated
280 Grand Avenue East
P.O. Box 1326
Chatham, Ontario
N7M 5R9

W.L. Sears
W.L. Sears and Associates Limited
455 Seaman Street
Stoney Creek, Ontario
L8E 2R2

F. Krizan
Sigma Engineering Group Limited
4610 Dufferin Street
Suite 201
Downsview, Ontario
M3H 4P8

S. Soudack
Sigmund Soudack & Associastes Limited
4800 Dufferin Street
Suite 100
Downsview, Ontario
M3H 5S8

H. Borgdorff
Reid & Associates Limited
143 Ferndale Drive
R.R. no 2
Barrie, Ontario
L4M 4S4

F.J. Reinders
F.J. Reinders and Associates Limited
7665 Hurontario Street
P.O. Box 278
Brampton, Ontario
L6V 2LI

B.M. Ross
B.M. Ross and Associates Limited
62 North Street
Goderich, Ontario
N7A 2T4

F. Schaeffer
Fred Schaeffer & Associates Ltd.
465 Wilson Avenue
Suite 202
Downsview, Ontario
M3H IT9

John H. McCalla
Oliver, Mangione, McCalla and Associates Limited
1755 Woodward Drive
Ottawa, Ontario , K2C OP9

J.S.R. Beck
C.C. Parker Consultants Limited
1400 Rymal Road East
Hamilton, Ontario
LOR IPO

R.I. Maksymec
Planmac Consultants Limited
3055 Lakeshore Blvd. West
Toronto, Ontario
M8V IK6

E.D. McCormick
McCormick, Rankin & Associates Limited
60 Briarwood Avenue
Mississauga, Ontario
L5G 3N6

P.B. Lawrence
Paul Lawrence Associates Limited
365 Evans Avenue
Suite 309
Toronto, Ontario
M8Z IK2

J.W. MacLaren
MacLaren Engineers Planners and Scientists Inc.
1220 Sheppard Avenue East
Suite 100
Willowdale, Ontario
M2K 2T8

K.A. McLennan
Marshall, Macklin, Monaghan Limited
275 Duncan Mill Road
Don Mills, Ontario
M3B 2YI

W.P.Buck
Inducon Consultants of Canada Limited
235 Yorkland Boulevard
Suite 1100
Willowdale, Ontario
M2J 4W9

E.L. Mercer
Robert Halsall & Associates Ltd.
20 Holly Street
Suite 200
Toronto, Ontario
M3S 3BI

E.P. Smith
Heatnwood Engineering Associates Ltd.
29 Duncan Avenue North
P.O. Box 190
Kirkland Lake, Ontario
P2N 3H7

S.G. Angus
Hooper & Angus Associates Ltd.
950 Yonge Street
Suite 502
Toronto, Ontario
M4W 2J7

S.J.G. Bird
Bird & Hale Limited
1263 Bay Street
Toronto, Ontario
M5R 2CI

M.R. Byrne
M.R. Byrne & Associates Limited
480 Guelph Line
Burlington, Ontario
L7R 3MI

P.C. Ellard
Ellard-Wilson Limited
3640 Victoria Park Avenue
Willowdale, Ontario
M2H 3B2

J.N. Galli
FENCO Consultants Ltd.
1 Yonge Street
Toronto, Ontario
M5E IE7

C.E. Stockman
Fodor Engineering Ltd.
111 Avenue Road
Suite 700
Toronto, Ontario
M5R 3L7

J.F. Gartner
Gartner Lee Associates Limited
Toronto-Buttonville Airport
Suite 10
Markham, Ontario
L3P 3J9

N.Eryou
Davis Engineering Limited
1481 Cyrville Road
Ottawa, Ontario
KIB 3L7

E.R. Bennett
Delcanda International Ltd.
1729 Bank Street, Suite 207
P.O. Box 8004
Ottawa, Ontario
KIG 3H6

J.J. Dennis
Dennis Consultants Limited
500 Barrydowne Road
Suites I & 2
Sudbury, Ontario
P3A 3T3

W.D. Aitken
D.F.A. Engineering Limited
450 Front Street West
Toronto, Ontario
M5V IB6

J. Chisvin
The ECE Group
205 Lesmill Road
Don Mills, Ontario
M3B 2VI

MANITOBA

R.E. Harrison
Teshmont Consultants Inc.
1146 Waverley Street
Winnipeg, Manitoba
R3T OP4

D.M. Kilgour
Crosier Kilgour & Partners Ltd.
330 St. Mary Avenue
Suite 550
Winnipeg, Manitoba
R3C 325

M. Gillman
Pulse Engineering Ltd.
538 Berry Street
Winnipeg, Manitoba
R3H OR9

W.M. Hanuschak
WM. Hanuschak & Associates Ltd.
26 Edmonton Street
Winnipeg, Manitoba
R3C IP7

H. Penner
Penner and Keeler Partners Limited
743 Ellice Avenue
Suite 201
Winnipeg, Manitoba
R3G OB5

W.H. Mitchell
Scouten, Mitchell, Sigurdson &
Associates Limited
297 Smith Street
Suite 300
Winnipeg, Manitoba
R3C IL3

J.L. Greer
W. L. Wardrop & Associates Ltd.
77 Main Street
Winnipeg, Manitoba
R3C 3HI

SASKATCHEWAN

V.G. Beckie
Beckie Hydrogeologists Limited
3806 Albert Street
Suite 201
Regina, Saskatchewan
S4S 3R2

R.J. Genereux
R.J. Genereux & Associates Limited
2060 Broad Street
Regina, Saskatchewan
S4P IY3

Grant t. Keith
The Keith Gabriel Partnership
766 Angus Street
Regina, Saskatchewan
S4T IX6

J. J. McCartan
McCartan, Gaudet & Associates Ltd.
325B - 5th Avenue North
Saskatoon, Saskatchewan
S7K 2P7

G.M. Pearson
Saskmont Engineering Company Limited
2400 College Avenue
Suite 500
Regina, Saskatchewan
S4P IC8

B.W. Kishchuk
Engineering Management Services Croscan Ltd.
308 - 5th Avenue North
P.O. Box 4042
Saskatoon, Saskatchewan
S7K 3TI

P. Machibroda
P. Machibroda Engineering Ltd.
2331 Millar Avenue
P.O. Box 1321
Saskatoon, Saskatchewan
S7K 3N9

Angus Butler Engineering Ltd.
1112 Morgan Avenue
Saskatoon, Saskatchewan
S7H 2R7

A.W. Fennell
Fennell Cochrane Associates Ltd.
2075 Hamilton Street
Suite 200
Regina, Saskatchewan
S4P 2EI

J.W. Rittinger
John W. Rittinger & Associates
151 - Ist Avenue N.E.
Swift Current, Saskatchewan
S9H 2BI

ALBERTA

Angus Butler Engineering (1980) Ltd.
1105 - 107 Street
Edmonton, Alberta
T5H 2Z6

C. MacFadyen
BBT Geotechnical Consultants Ltd.
7708 Wagner Road
Edmonton, Alberta
T6E 5B2

H.W. Klassen
The Klassen Angus Group Ltd.
720 - 11th Avenue South West
Calgary, Alberta
T2R OE4

S.E. Lawrence
Associated Engineering Services Ltd.
13140 St. Albert Trail
Edmonton, Alberta
T5L 4R8

S.G. Jackson
SNC Consultants Ltd.
10130 - 103 Street
Edmonton, Alberta
T5J 3N9

N.L. Reid
Reid, Crowther & Partners Limited
7410 Blackfoot Trail S.E.
P.O. Box 5600, Postal Station "A"
Calgary, Alberta
T2H IX9

D.D. Mears
Stanley Associates Engineering Ltd.
11810 Kingsway Avenue
Edmonton, Alberta
T5G OX5

A.R. Pasini
Underwood McLellan Ltd.
17007 - 107 Avenue
Edmonton, Alberta
T5S IG3

D.J. Sampson
T. Lamb, McManus and Associates Ltd.
1011 Glenmore Trail S.W.
Suite 300
Calgary, Alberta
T2V 4R6

E.W. Brooker
EBA Engineering Consultants Ltd.
14535 - 118th Avenue
Edmonton, Alberta
T5L 2M7

Ian F.B. McBride
The Engineers Collaborative
6810 - 104 Street
P.O. Box 4546
Edmonton, Alberta
T6E 5G4

H.L. Morrison
Hardy Associates (1978)Ltd.
5555 Calgary Trail, Weber Centre
Suite 1350
Edmonton, Alberta
T6H 4J9

W. Eadie
Kasten, Eadie Engineering Ltd.
10121 - 124th Street
Edmonton, Alberta
T5N IP5

COLOMBIE BRITANNIQUE
(BRITISH COLUMBIA)

W.E. McIntyre
The UMA Group
1066 West Hastings, Suite 1700
P.O. Box 12546 Oceanic Plaza
Vancouver, British Columbia
V6E 3X2

S.J. Cunliffe
Willis, Cunliffe, Tait & Co. Ltd.
827 Fort Street
Victoria, British Columbia
V8W IH6

R. Martin
Aplin & Martin Engineering Ltd.
9238 - 120th Street
Surrey, British Columbia
V3V 4B7

J. E. Snowball
McKenzie, Snowball, Skalbania
& Associates Ltd.
1510 Alberni Street
Vancouver, British Columbia
V6G IA9

E.J. Klohn
Klohn Leonoff Ltd.
10180 Shellbridge Way
Richmond, British Columbia
V6X 2W7

R.G. Fraser
Terre Engineering Laboratories Ltd.
1350 William Street
Vancouver, British Columbia
V5P 2P5

J. Rockingham
Rockingham Engineering Limited
1551 Johnston Street
Suite 8
Vancouver, British Columbia
V6H 3R9

J.A. Merchant
Swan Wooster Engineering Company Ltd.
1525 Robson Street
Vancouver, British Columbia
V6G IC5

B. Babicki
Boque Babicki & Associates Limited
1235 West Pender Street
Vancouver, British Columbia
V6E 2V6

D.W. Brown
Brown Strachan Associates
1290 Homer Street
Suite 002
Vancouver, British Columbia
V6B 2Y5

K.A. Henry
CBA Engineering Ltd.
1425 West Pender Street
Vancouver, British Columbia
V6G 2S3

D.M. Kilgour
Crippen Consultants C
Crippen International
224 West Esplanade
North Vancouver, British Columbia
V7M IA4

Wm.C. McKenzie
Choukalos Woodburn McKenzie Maranda Ltd
1666 West Broadway
Vancouver, British Columbia
V6J IX6

R.G. Doyle
Cook Pickering & Doyle Ltd.
141 East 7th Avenue
Vancouver, British Columbia
V5T IM5

J.N. Keen
Keen Engineering Co. Ltd.
545 Clyde Avenue
Suite 214
West Vancouver, BRITISH COLUMBIA

J.K. Wittig
J.K.W. Engineering limited
1090 West Georgia Street
Suite 390
Vancouver, British Columbia
V6E 3V7

H. Kolbeins
Robertson, Kolbeins, Teevan
& Gallaher Ltd.
1965 West 4th Avenue
Suite 202
Vancouver, British Columbia
V6J IM8

C.C. Midwinter
Sandwell & Company Limited
1550 Alberni Street
Suite 601
Vancouver, British Columbia
V6G IA4

T.H. Thomson
T.M. Thomson & Associates Ltd.
1006 Government Street
Victoria, British Columbia
V8W IX7

G.F. Buck
Thurber Consultants Ltd.
4475 Viewmont Avenue
Suite 210
Victoria, British Columbia
V8Z 6L8

B.H. Levelton
B.H. Levelton & Associates Ltd.
8805 Osler Street
Vancouver, British Columbia
V6P 4GI

R.A. Brocklebank
McElhanney Surveying & Engineering Limited
1166 Alberni Street
Vancouver, British Columbia
V6E IA5

R.P. Mellema
Ralph P. Mellema Engineering Ltd.
704 - 6th Street
Suite 1
New Westminster, British Columbia
V3L 3C5

J. Warne
Pomeroy Engineering Limited
3455 Victoria Drive
Suite 200
Vancouver, British Columbia
V5N 4M5

S.W. Faliszewski
Faliszewski Engineering Ltd.
1157 Melville Street
Suite 2
Vancouver, British Columbia
V6E 2X5

H.R.M. Murray
Graeme & Murray Consultants Limited
1137 Yates Street
Victoria, British Columbia
V8V 3NI

A.McDougall
Sir Wm. Halcrow & Partners (B.C.)
1520 Pemberton Avenue
North Vancouver, British Columbia
V7P 2S2

T.A. Creaney
INTEG - Interncontinental Engineering Limited
1155 West Pender Street
Vancouver, British Columbia
V6E 2P4

W.A. Ker
Ker, Priestman & Associates Ltd.
2659 Douglas Street
Suite 300
Victoria, British Columbia
V8T 4M3

APPENDIX 3

LIST OF THE MAIN ORGANIZATIONS AND FIRMS INVOLVED IN POLYMER CONCRETE AND QUOTED IN THIS REPORT

ACODRAIN INC.
29525 Chagrin Blvd
Cleveland, Ohio 44122
U.S.A.

ANRÖCHTER RINNE
Siemensstrabe 1
Postf 1150
4783 Anröchte
WEST GERMANY

ARCHITECTURAL RESEARCH
CORPORATION
13030 Wayne Rd
Livonia, Michigan 48150
U.S.A.
TELEX: 230177

BARBER-GREENE CO.
400 North Highland Avenue
Aurora, Illinois 60507
U.S.A.

B.B.G., BELZILE, BRASSARD,
GALLIENNE ET ASSOCIÉS
Architectes
477, boul. Champlain
Québec, Québec
G1K 4J4

BETONWERKE
Munderkingen Gmbh (Bwm)
7932 Munderkingen
Postfach 4
WEST GERMANY

BLACHFORD LTD.
977 rue Lucien L'Allier
Montréal, Québec
H3G 2C3
TEL: (514) 866-9775

BROOK HAVEN NATIONAL LABORATORY
Upton, Long Island
New York 11973
U.S.A.

BUREAU DE TRANSPORT DE LA
COMMUNAUTÉ URBAINE DE MONTRÉAL
2580, boul. St-Joseph
Montréal, Québec
H1Y 2A2

CANFARGE LTÉE
Div. Francon
8300, boul. Pie IX
Montréal, Québec
H1Z 3T6

CHEMOR CORP. LTD.
236, St-Augustin
Montréal, Québec
H4C 2N6

DIVERSIFIED PRODUCTS
309-A Williamson Ave.
Opelika, Alabama 36801
U.S.A.

DUROPLASSTEIN GMBH
3549 Volkmarsen
Postf. 1170
ALLEMAGNE DE L'OUEST

ELECTRIC POWER RESEARCH
INSTITUTE (EPRI)
Palo Alto Box 10412
California 94303
U.S.A.

FRC COMPOSITES LTD.
1993 Leslie
Toronto, Ontario
TÉL: (416) 449-1405

FRITZ STUDER SA
CH-3601 Glockenthal
Thoune
SUISSE

GEMITE
328 Carlingview Dr.
Toronto, Ontario

GORENJE
63320 Velenje
Celjska 5-A
YUGOSLAVIA
TELEX: 33-616-YUSOGOR

H.B. FULLER CANADA INC.
88, Industrielle
Boucherville, Québec
J4B 2X2

INSTITUT NATIONAL DES
INDUSTRIES EXTRACTIVES (INIEX)
200, rue du Chéra
B-4000 Liège
BELGIQUE

JANIN CONSTRUCTION LTÉE
433, Grande-Allée est
Québec, Québec
G1R 2J5

KYOTO UNIVERSITY
Sakyo-Ku
Kyoto
JAPAN

LINDSEY INDUSTRIES
Azusa
California 91702
U.S.A.

MINISTÈRE DES TRANSPORTS DU QUÉBEC
Direction des structures
200, rue Dorchester sud
Québec, Québec
G1K 5Z1

NIHON UNIVERSITY
Koriyama
Fukushima
JAPAN

NIPPON TLELEPHONE AND
TELEGRAPH PUBLIC CORPORATION (NTT)
Engineering Bureau
Chiyoda-Ku
Tokyo
JAPAN

PANELCRAFT BV
Postbus 8
N4-4040 D
Kesteren
PAYS-BAS

PENNSYLVANIA POWER AND LIGHTS COMP.
Allentown
Pennsylvania
U.S.A.

PLASTIBÉTON INC.
5600, Hochelaga
Suite 300
Montréal, Québec
H1N 3L7

POWER L COMMUNICATION SYSTEM
615 Noyth
San José, California 95113
U.S.A.

RESPECTA - BAUMASCHINENGENSELLSCHAFT MBH
Steinstrasse 34
D-4000 Düsseldorf
FED. REP. GERMANY

ET

RESPECTA AMERICA INC.
2668 American Lane
Elk. Grove Ill. 60007
TELEX 206 984

SAFAMA ET CIE
14, rue Chevreul
49000 Angers
FRANCE

SIKA CANADA
601, avenue Delmar
Pointe-Claire, Québec
H9R 4A9
TEL: (514) 697-2610

STERNSON
22 Mohawk St.
P.O. Box 130
Brantford, Ontario
N3T 5N1

VENUS PRODUCTS INC.
1862 Ives Avenue
Kent, Washington 98031
U.S.A.
TELEX: 32-9498

WEEGELS BETONFABRIEK BV
Jan Van Der Croonstraat 40
6001 Ah Weert
HOLLAND
TELEX: 37599 WGELS NL

POOR

QUALITY

ORIGINAL